

# New Era of Air Quality Monitoring over Asia from Space - GEMS



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# Outline

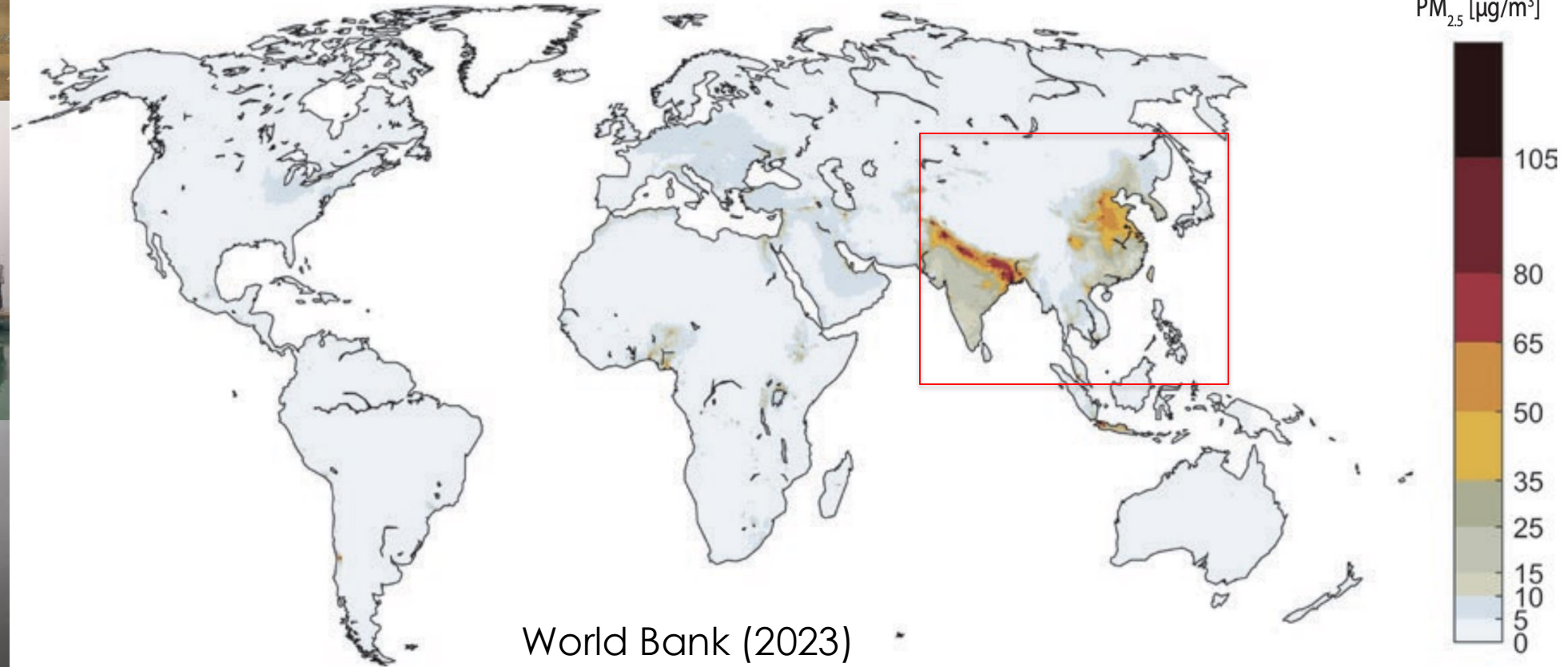


- Introduction
  - Satellite Remote Sensing of Atmospheric Composition
  - GEMS Development
  
- GEMS – A New Era of Air Quality Observation from GEO
  - Data Products
  - Updates
  - Validations
  
- Summary

# Air Pollution in Asia



a. Global PM<sub>2.5</sub> exposure

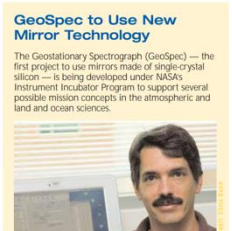
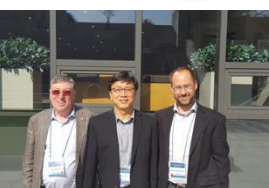
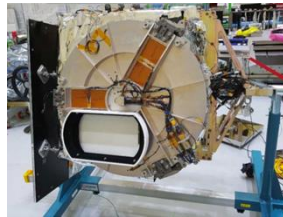
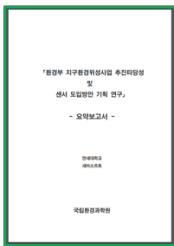
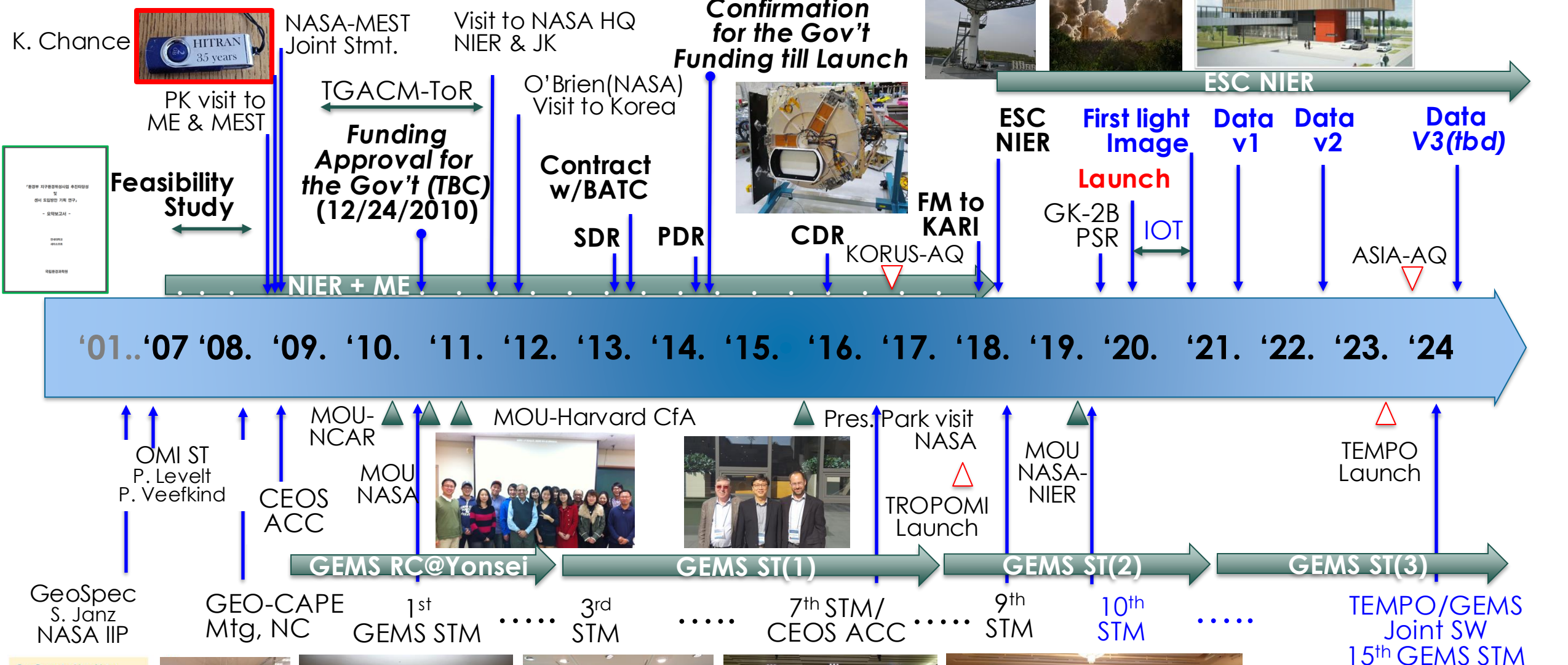


- Annual premature death of ~7M people globally (WHO).
- Home to 50% of global population.
- Most share common sources with greenhouse gases.





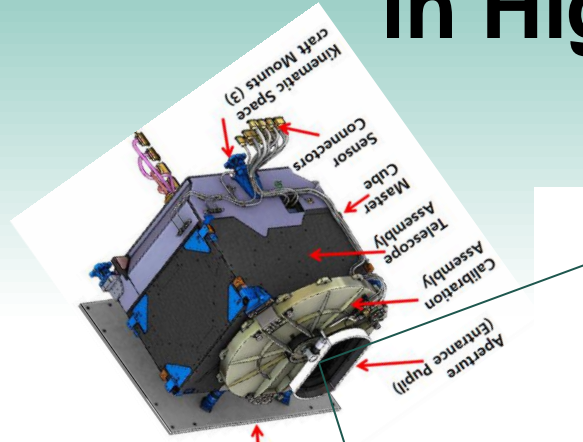
# History of GEMS Development



National Institute of Environmental Research

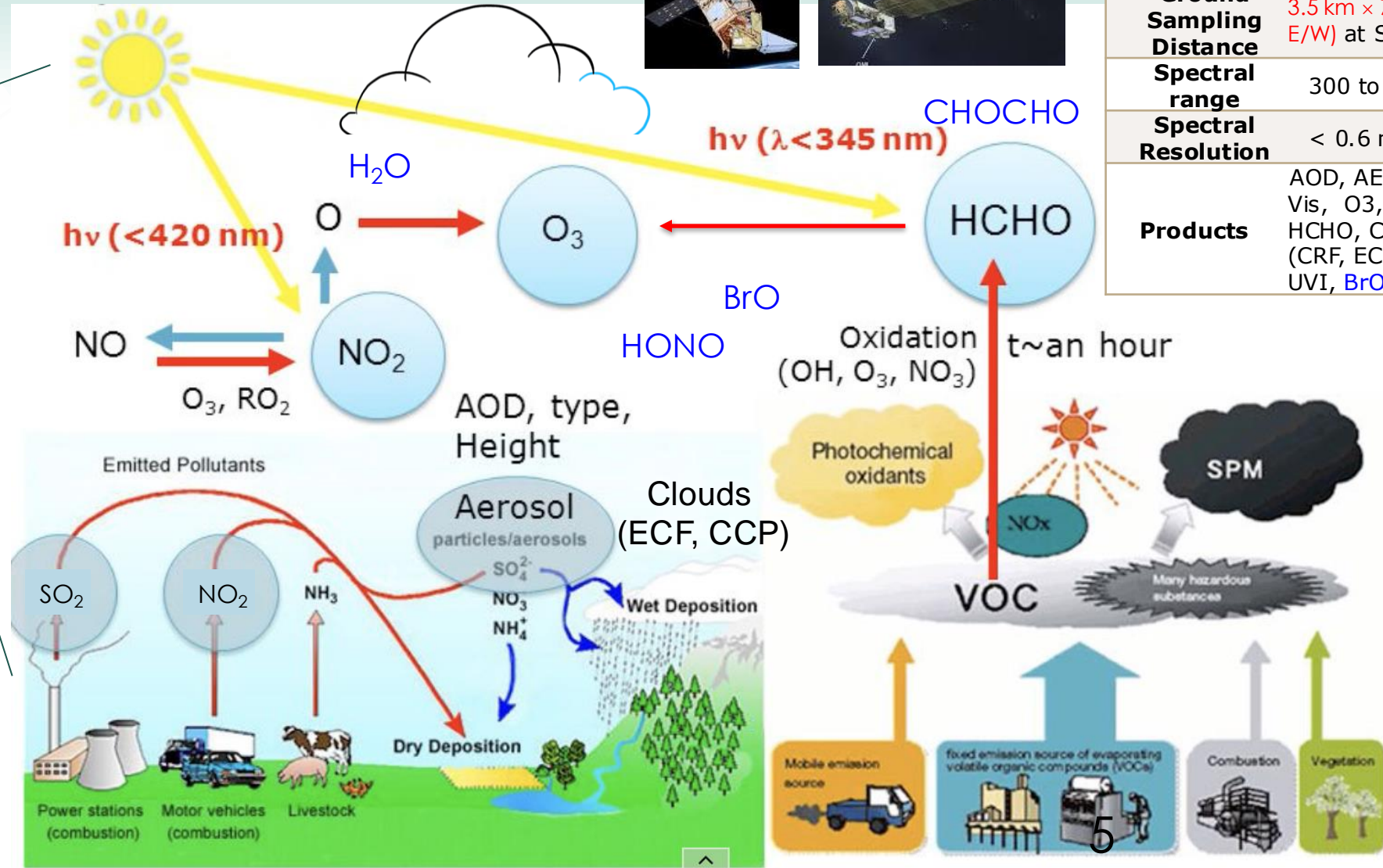


# GEMS – Air Quality Observation over Asia in High Spatio-temporal Resolution



**NIER/KARI  
GEMS  
(2020-present)**

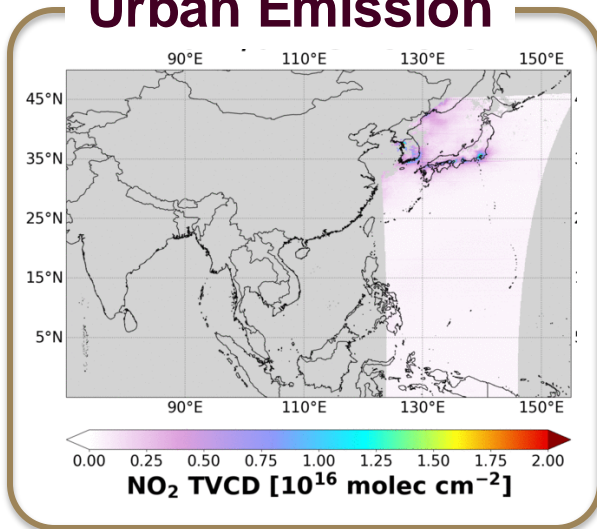
- ✓ Daily operation since Nov 2020
- ✓ Ver.2 data release in Nov., 2022
- ✓ Updated ver. data release in 2024



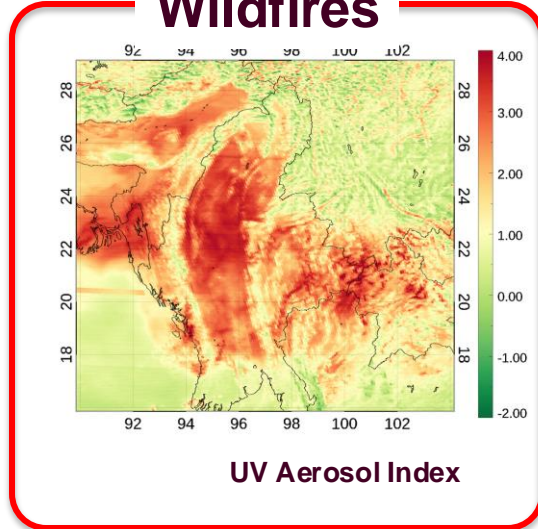
System Attributes	Requirements
<b>Lifetime</b>	> 10 years
<b>Field of Regard</b>	N/S rng: 45°N-5°S E/W rng: 75°E-145°E orbital pos.: 116.2°E - 128.2°E
<b>Ground Sampling Distance</b>	3.5 km × 7.7 km (N/S × E/W) at Seoul, Korea
<b>Spectral range</b>	300 to 500 nm
<b>Spectral Resolution</b>	< 0.6 nm
<b>Products</b>	AOD, AEH, AI-UV & Vis, O3, NO2, SO2, HCHO, CHOCHO, Cl d (CRF, ECP), Surface, UVI, BrO, H2O, HONO

# GEMS Data Products

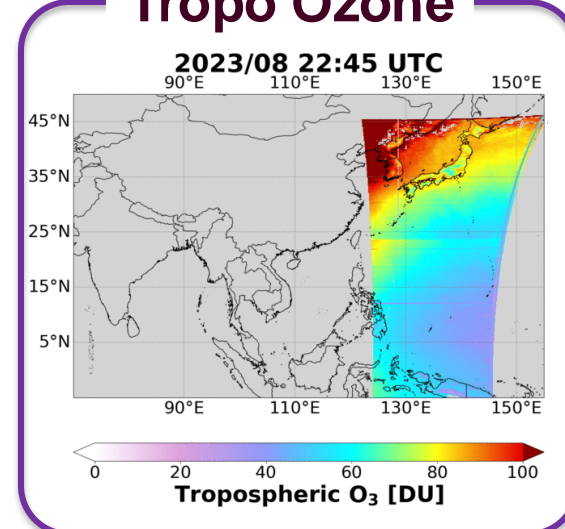
## Urban Emission



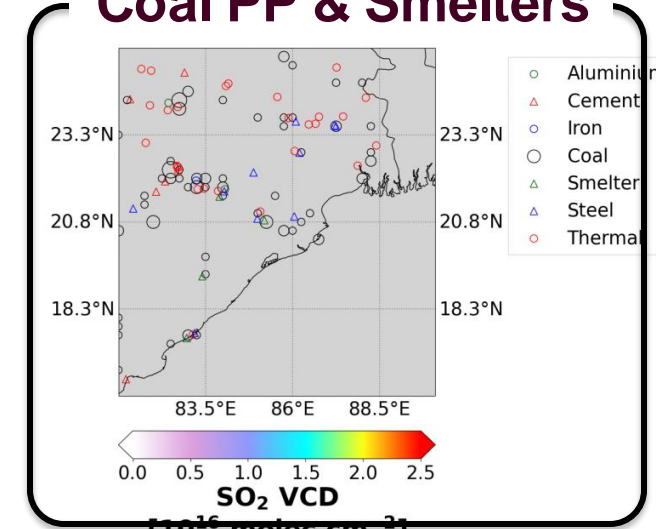
## Wildfires



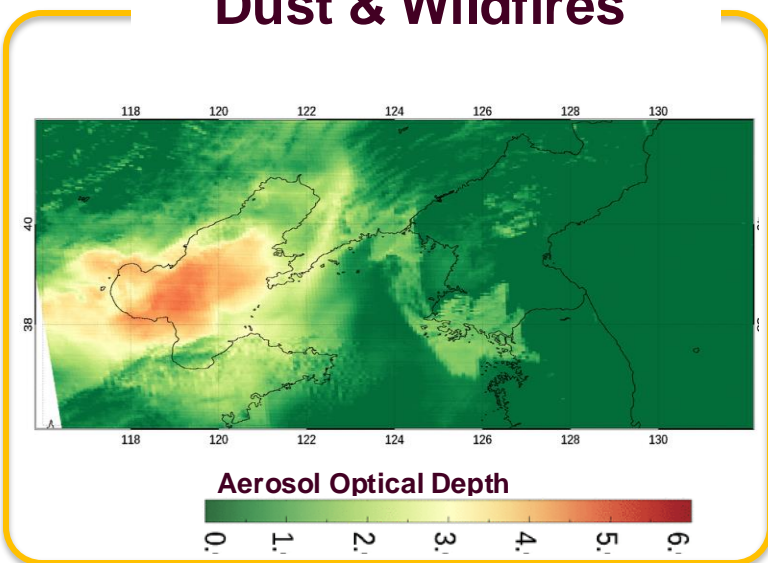
## Tropo Ozone



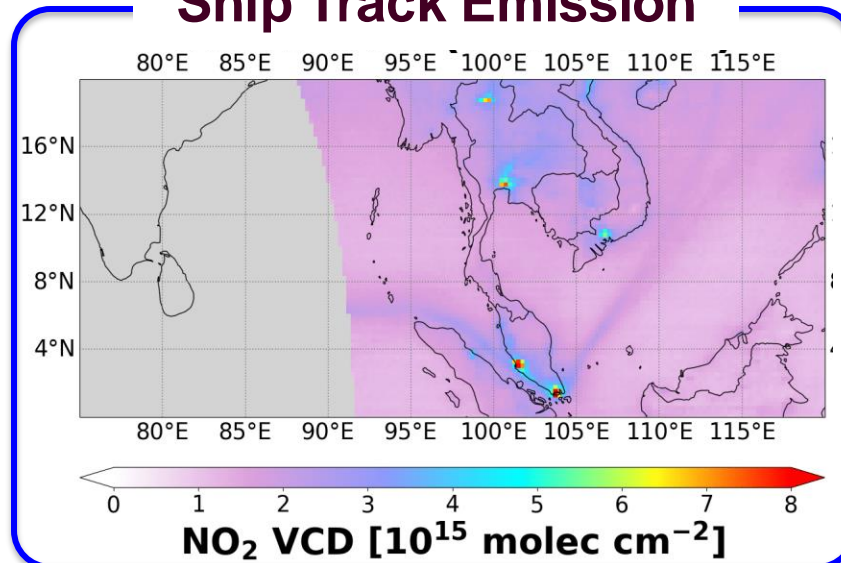
## Coal PP & Smelters



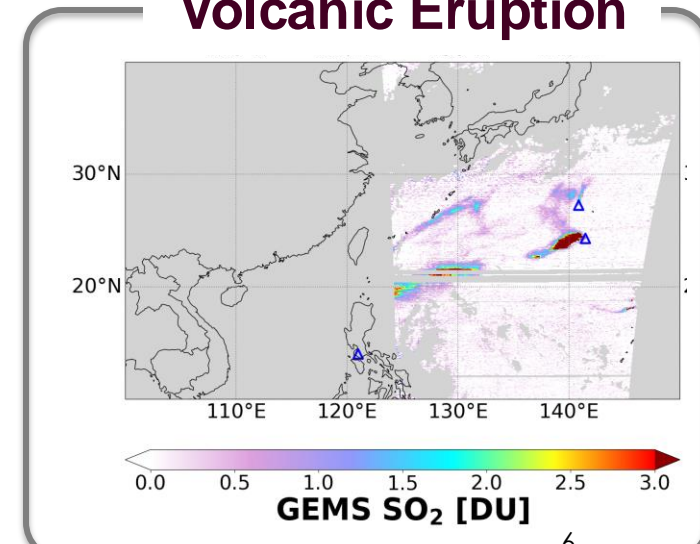
## Dust & Wildfires



## Ship Track Emission



## Volcanic Eruption

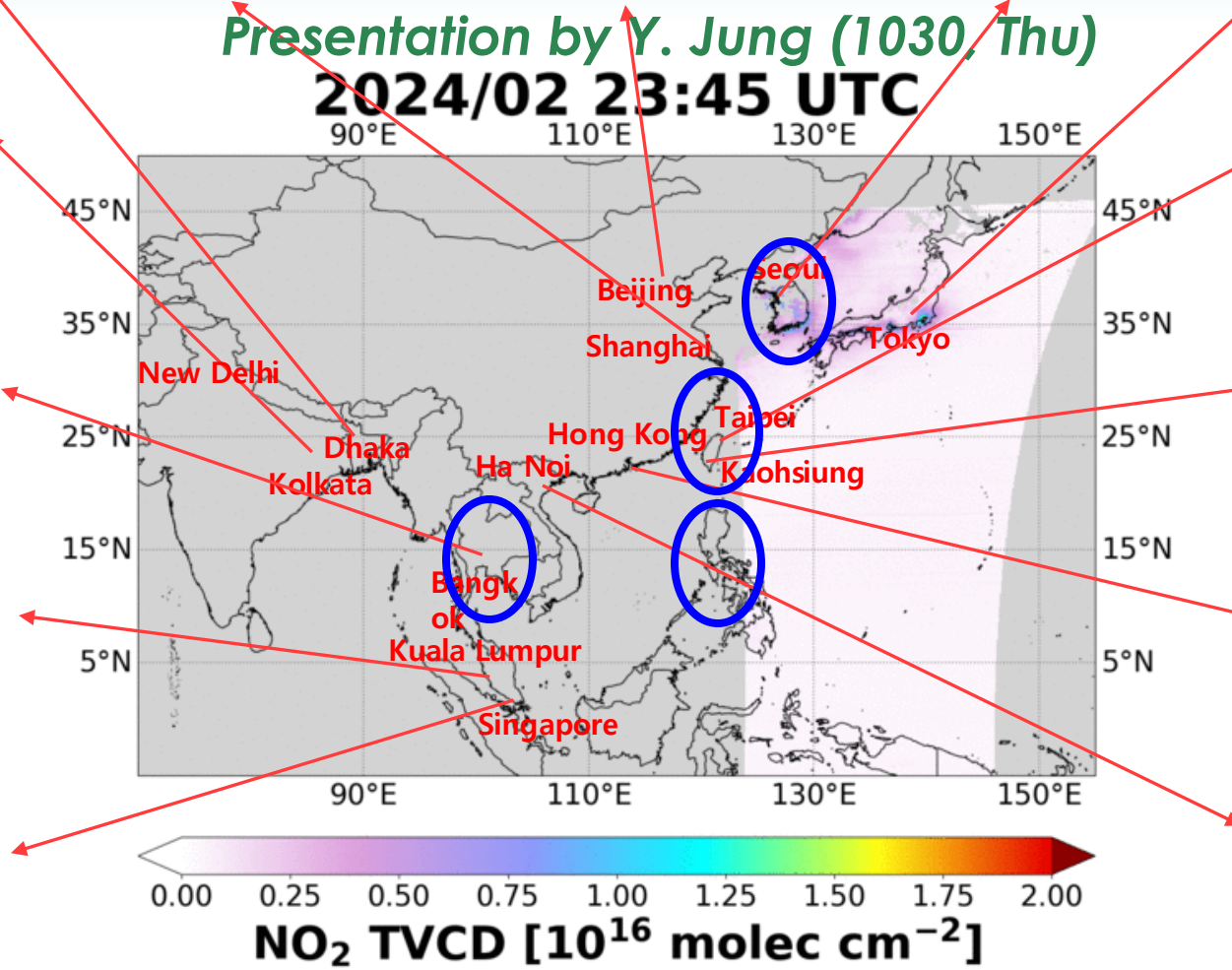
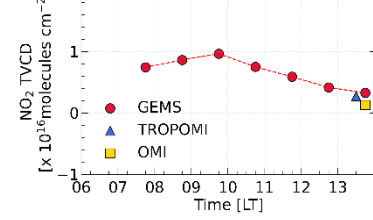
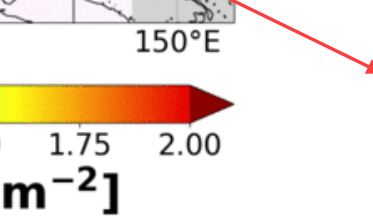
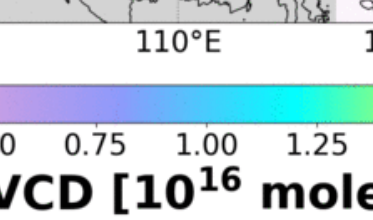
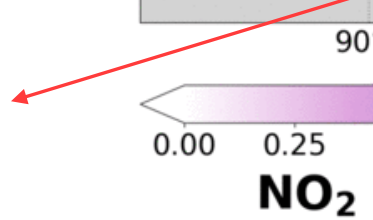
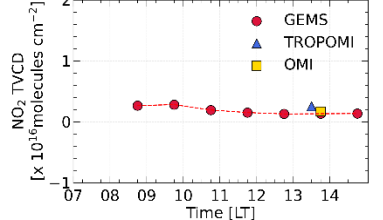
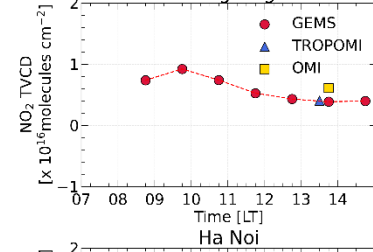
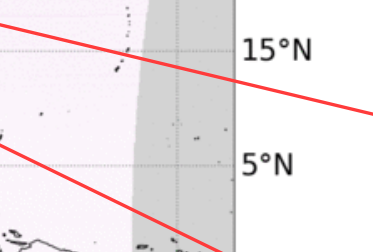
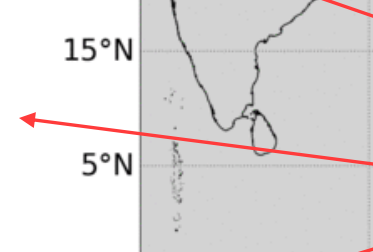
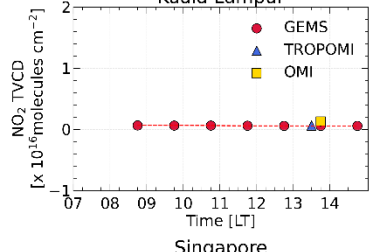
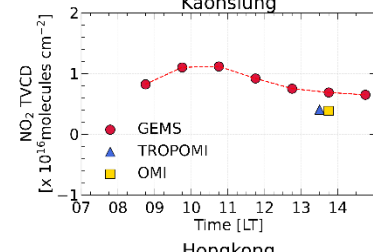
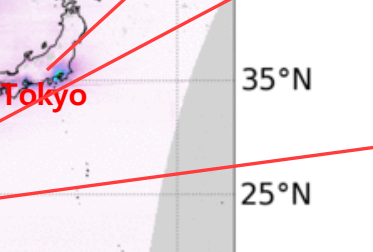
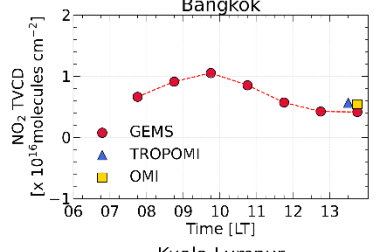
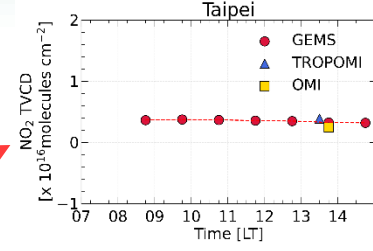
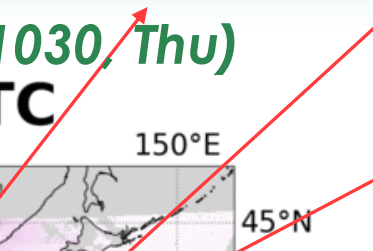
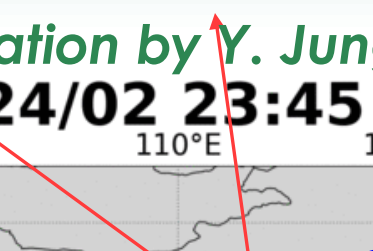
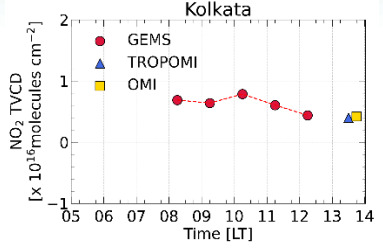
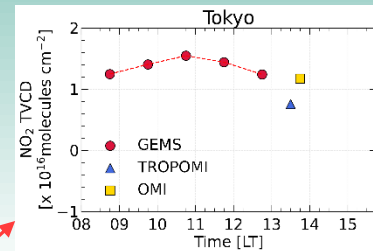
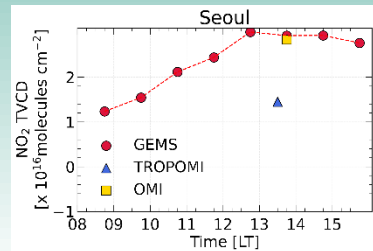
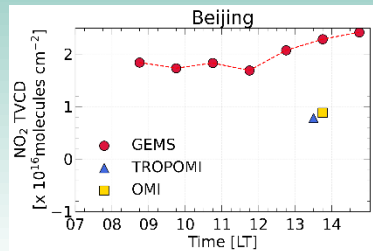
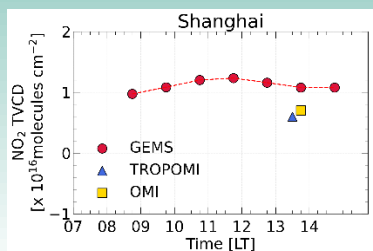
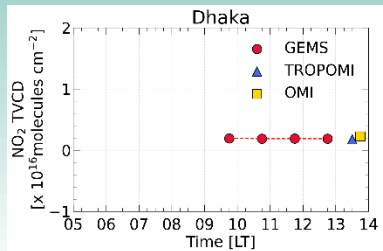




# Urban Hotspots : NO<sub>2</sub> v3

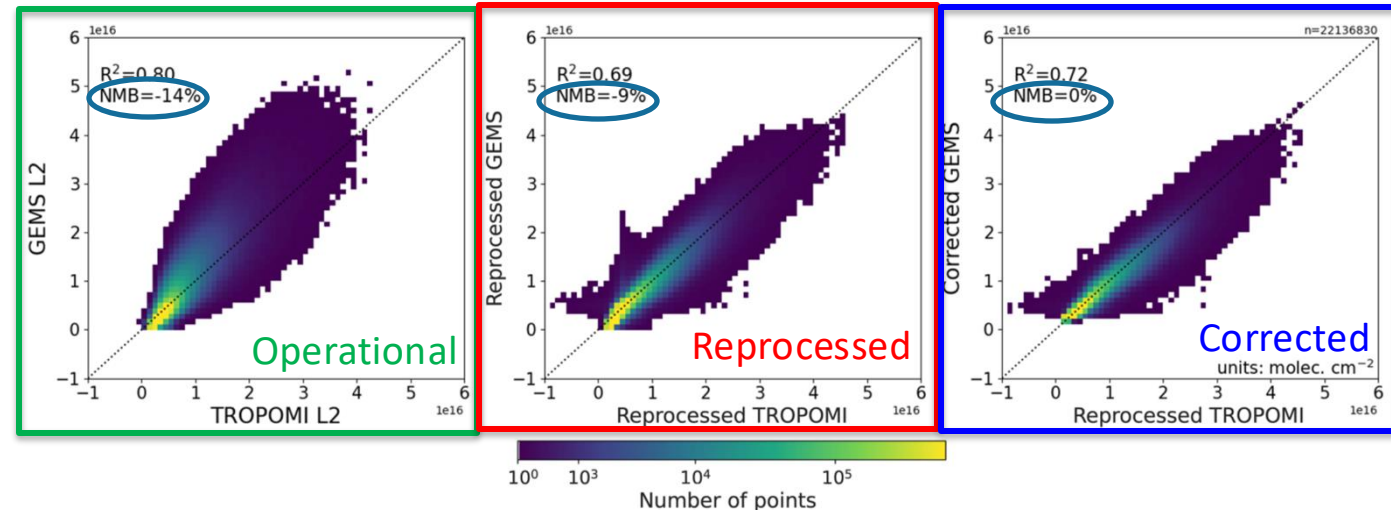
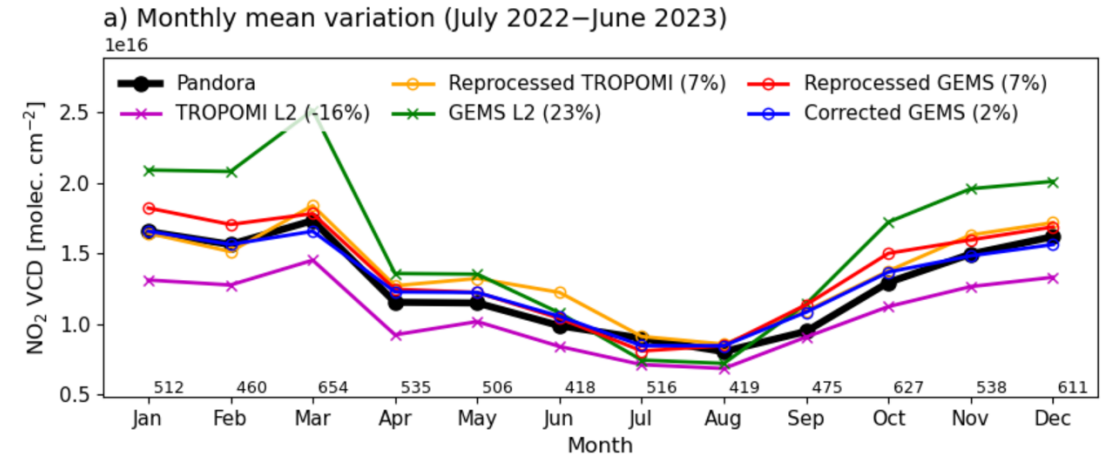
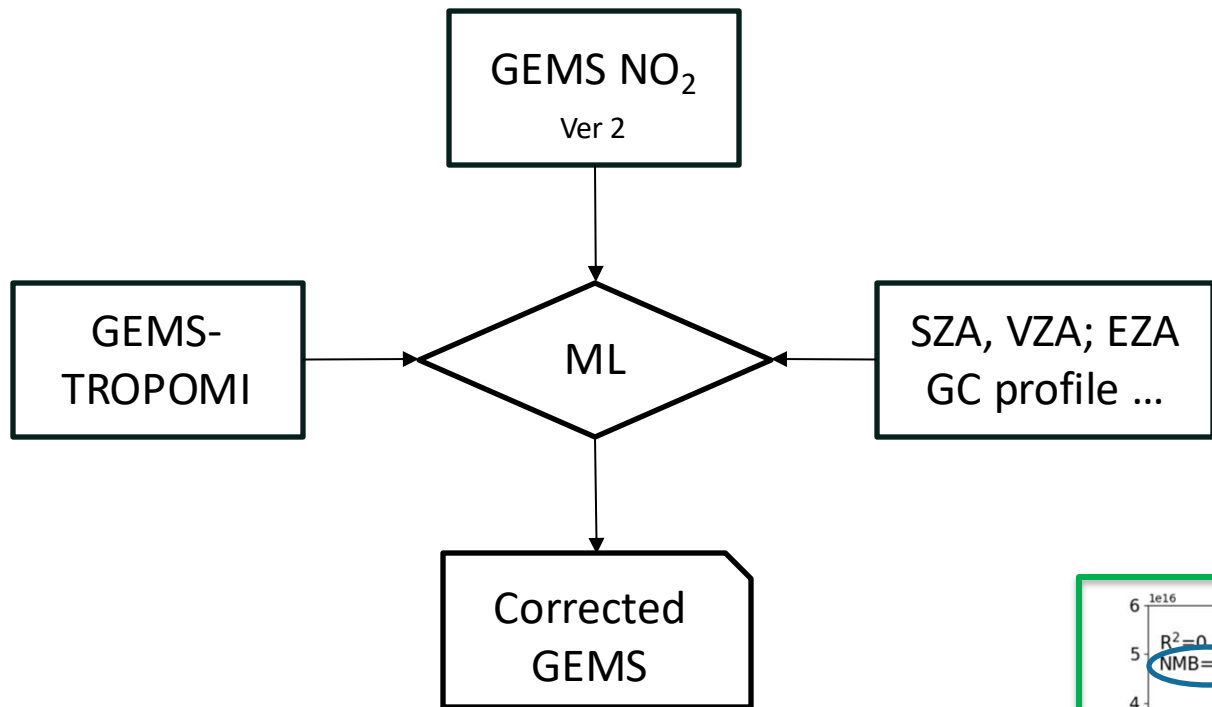


Presentation  
 by J.  
 Crawford  
 (1030, Fri)

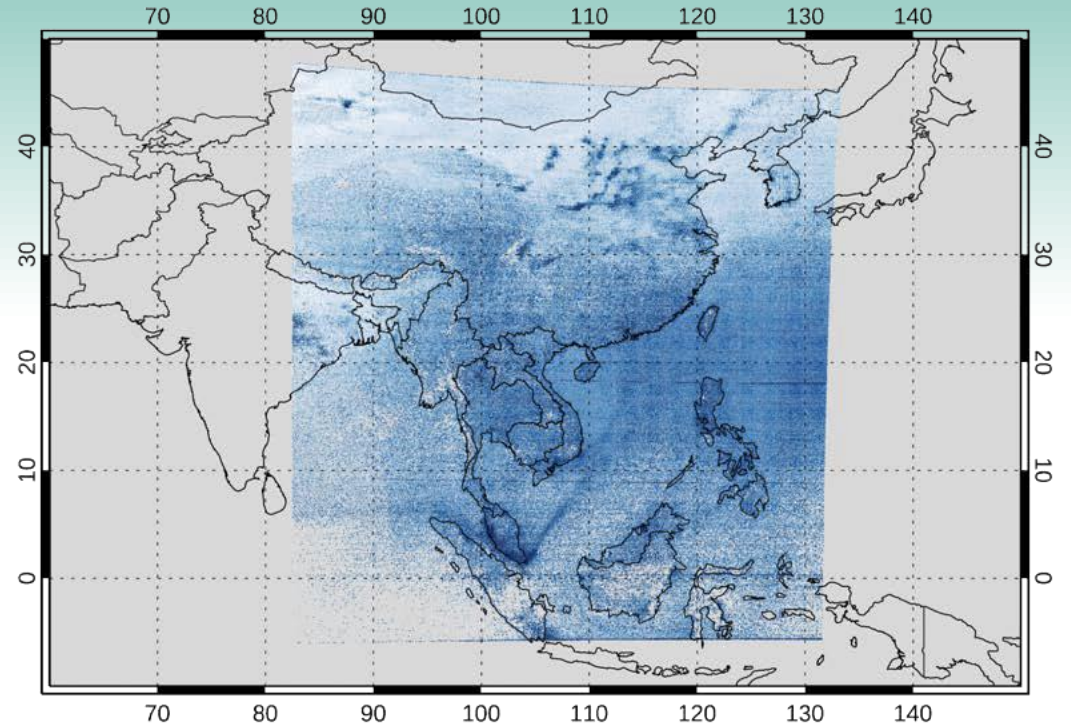
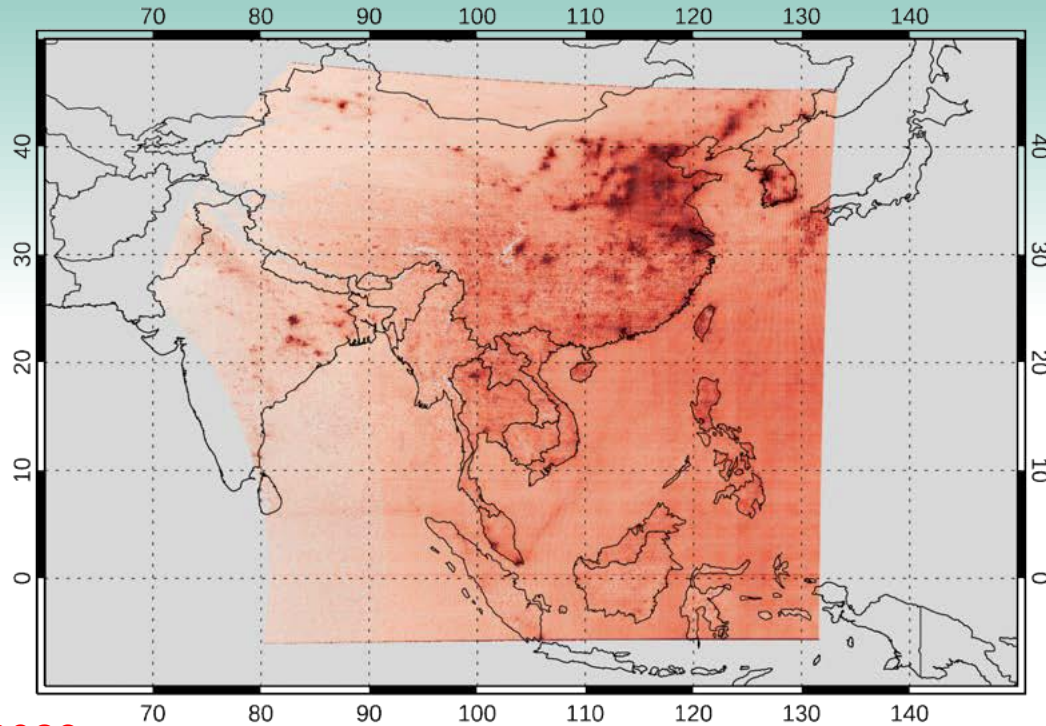




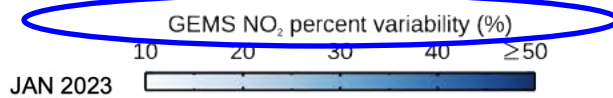
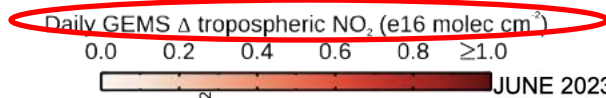
# ML-based Bias Correction



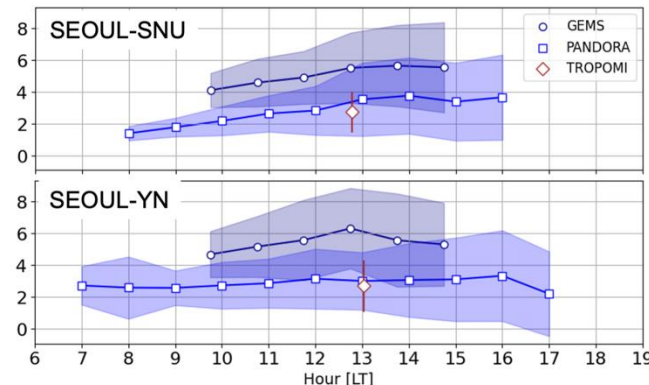
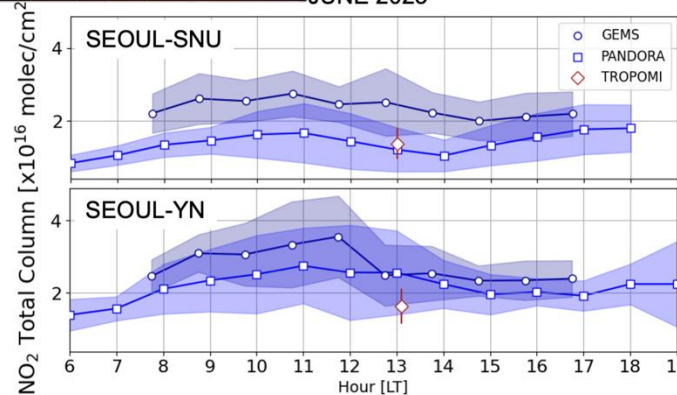
# Diurnal Variations of NO<sub>2</sub> in Urban Area



June 2023:



Morning peak in NO<sub>2</sub>, followed by a decrease through early afternoon.



Presentation  
by D. Edwards  
(1330, Thu)

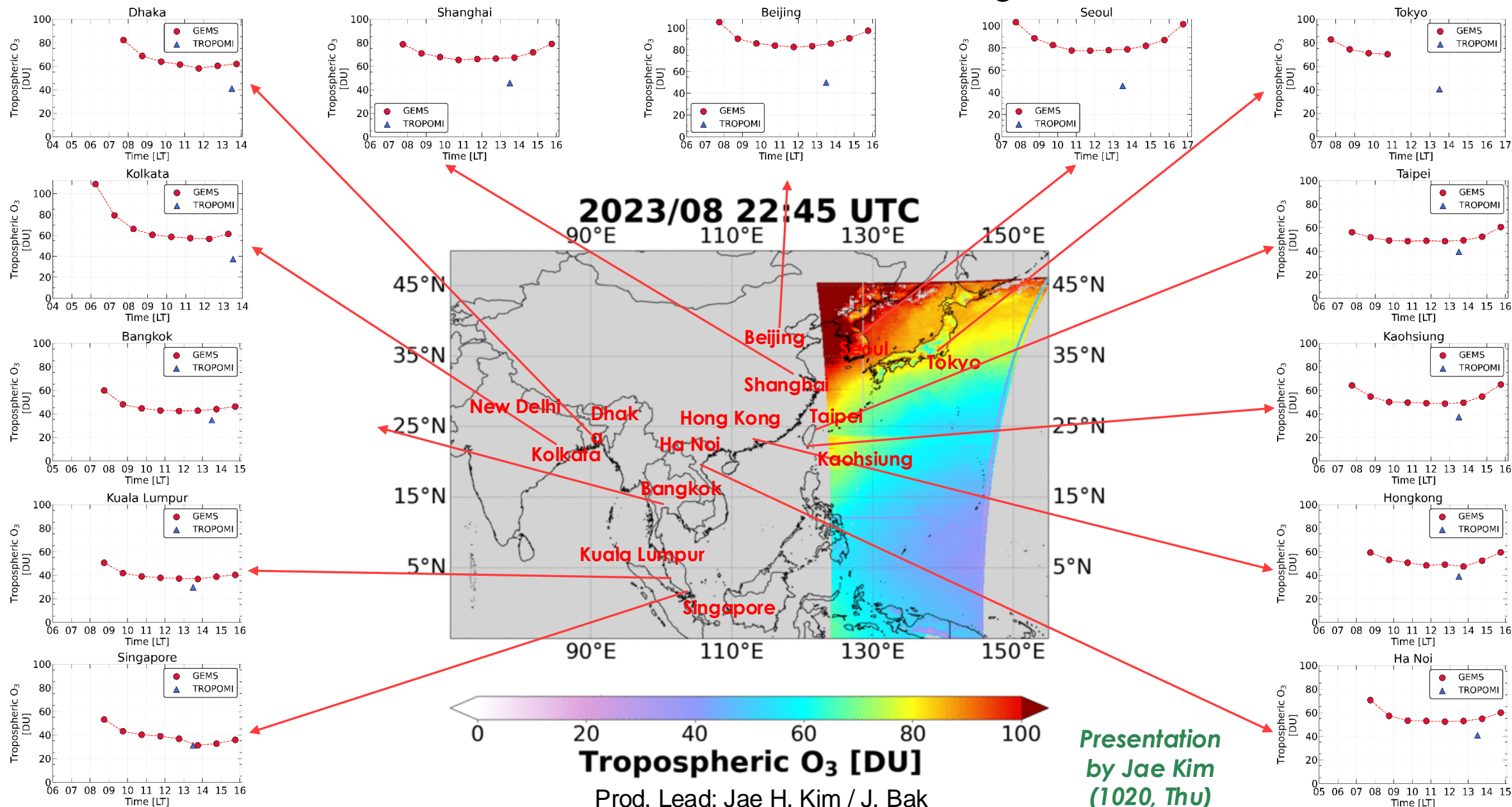
Edwards et al. (AMT, 2024)

**The positive bias of GEMS relative to Pandora is more pronounced in January.**

\* GEMS Troposphere O<sub>3</sub> v2.0 product

\* 2023/08/01 – 2023/08/31

# Tropospheric O<sub>3</sub> v2

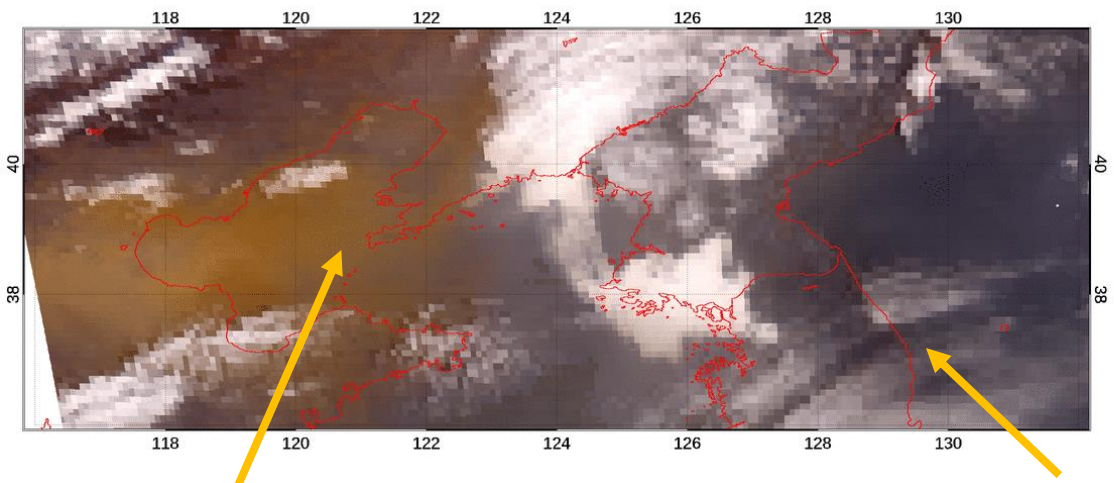




# Dust & Wildfire events

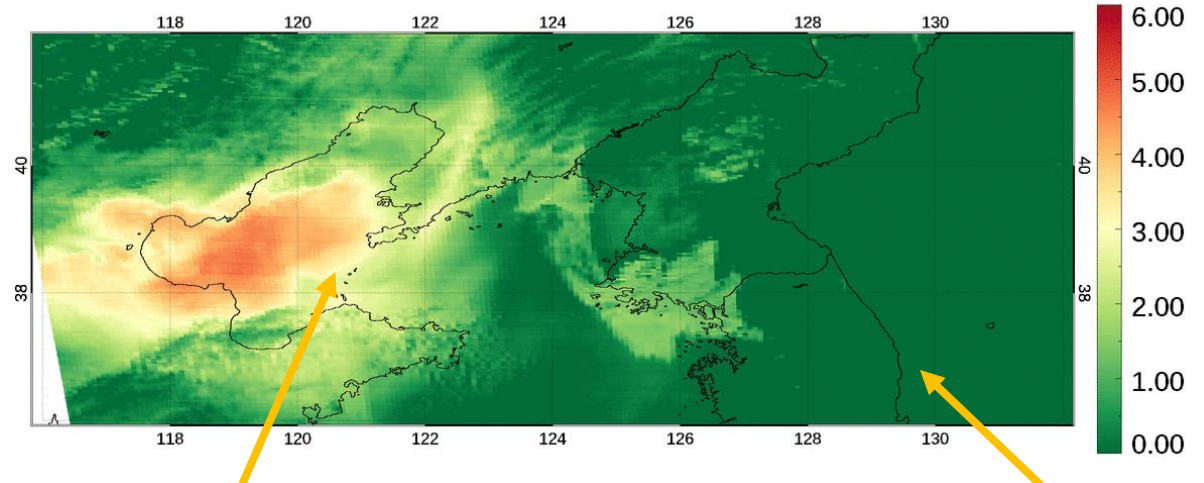
fRGB

GEMS False RGB  
2022/03/04 00:45 UTC



GEMS UVAI  
2022/03/04 00:45 UTC

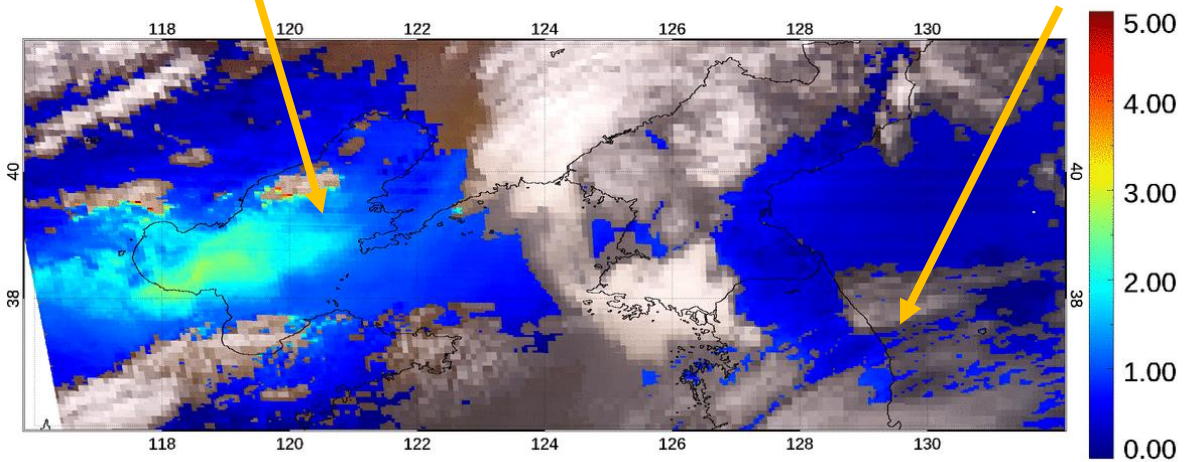
UVAI



Dust

GEMS AOD 443 nm  
2022/03/04 00:45 UTC

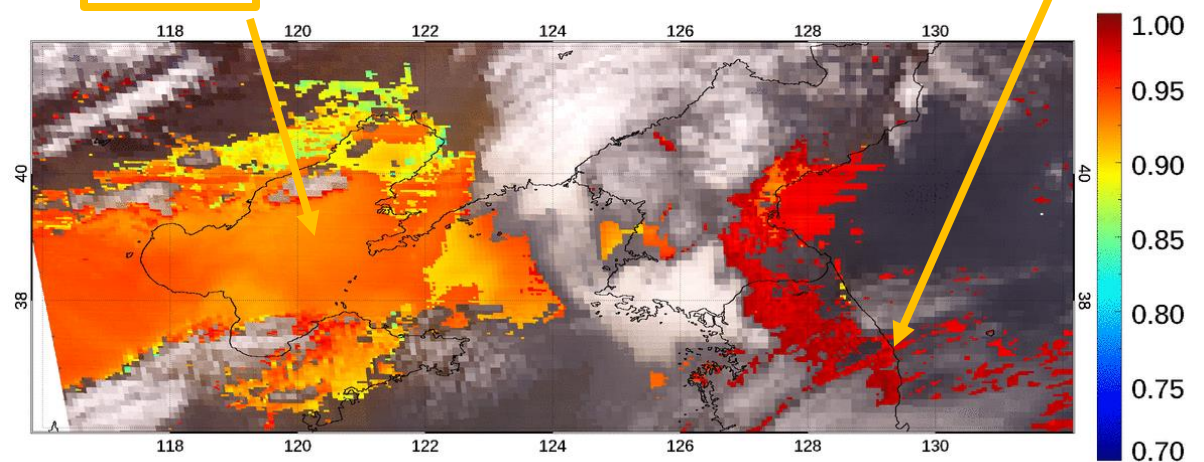
Wildfire



Dust

GEMS SSA 443 nm  
2022/03/04 00:45 UTC

Wildfire



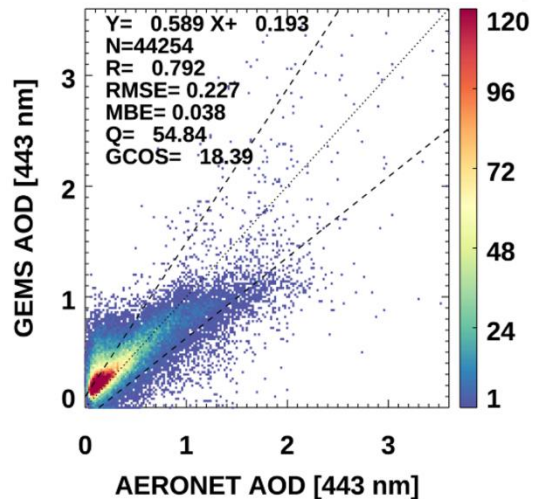
AOD

SSA

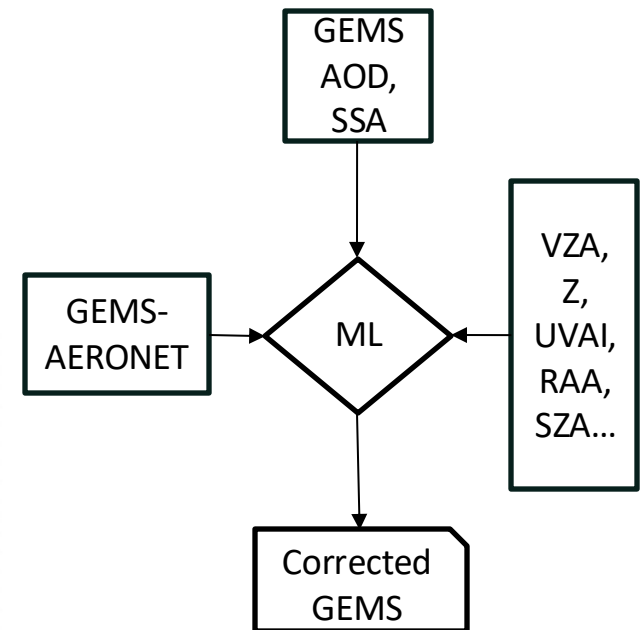
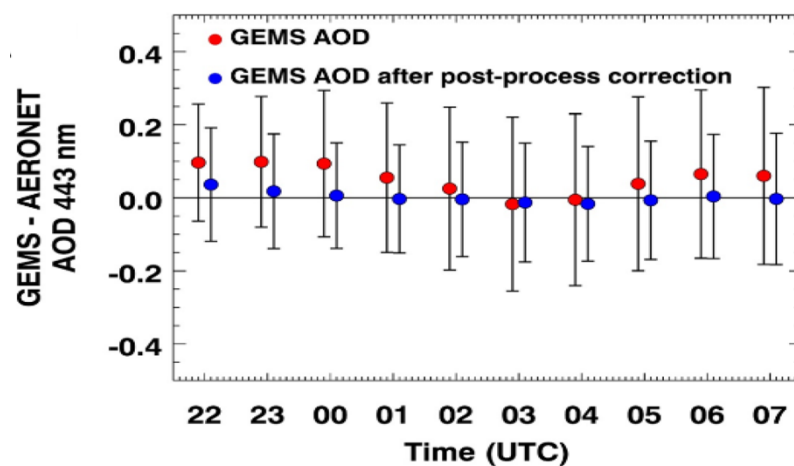
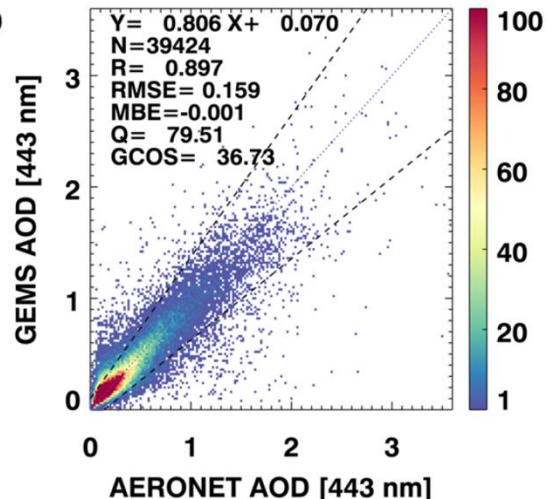
# Aerosol – post-processing

AOD

V2.1



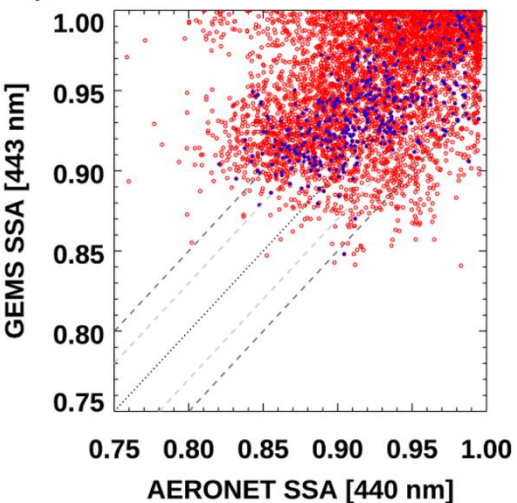
Post-processing



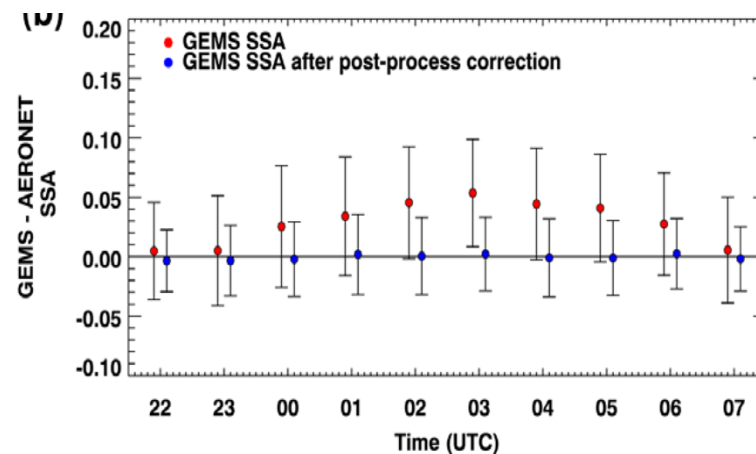
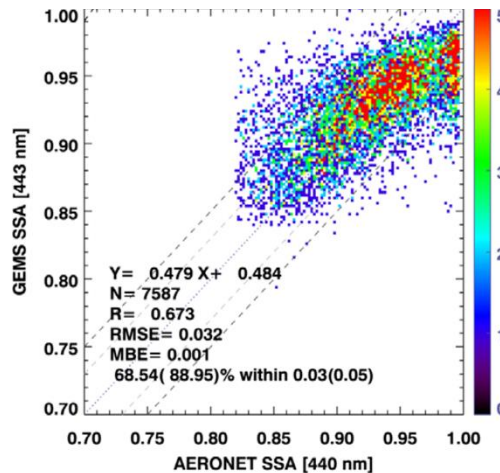
[Cho et al., AMT, 2024]

SSA

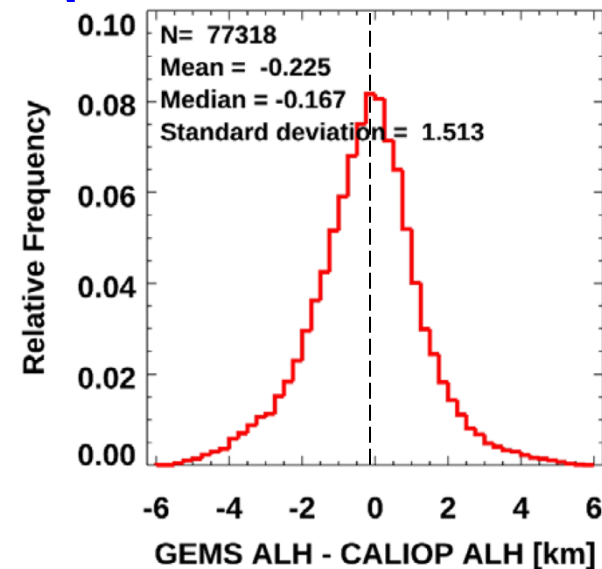
V2.1



Post-processing

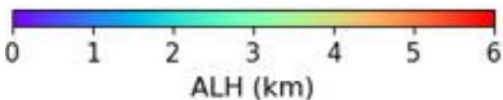
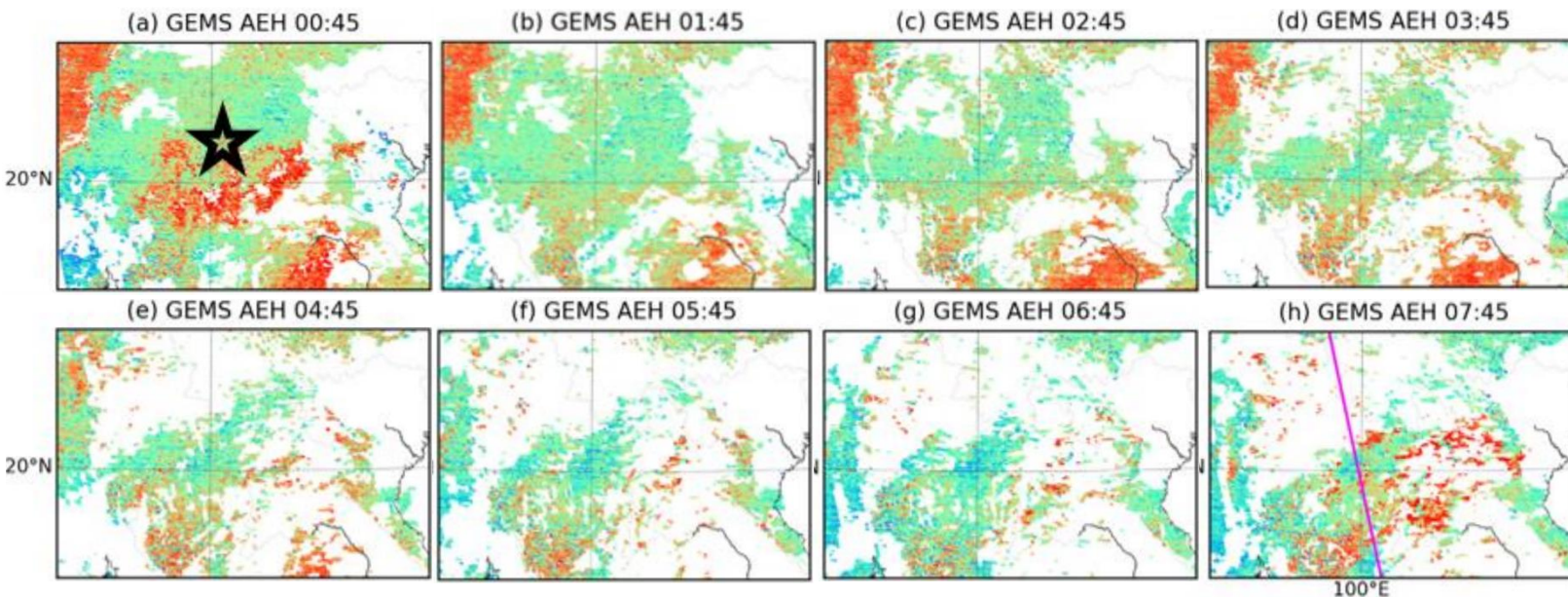


ALH

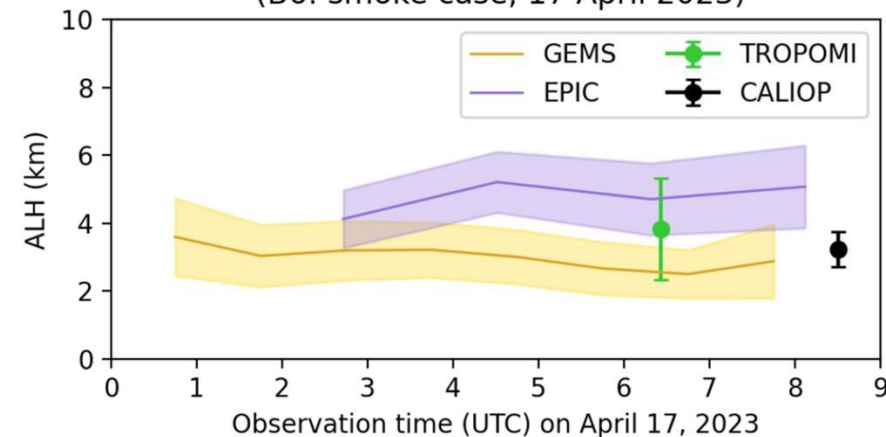




# ALH from O<sub>2</sub>(O<sub>2</sub>) bands of GEMS, EPIC, & TROPOMI

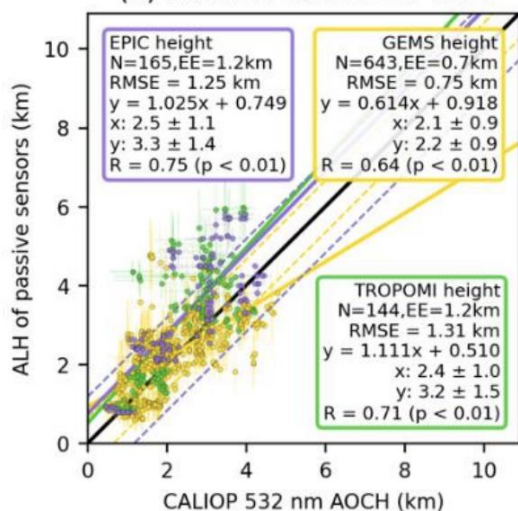


Regional averaged ALH for absorbing aerosols (B6: smoke case, 17 April 2023)

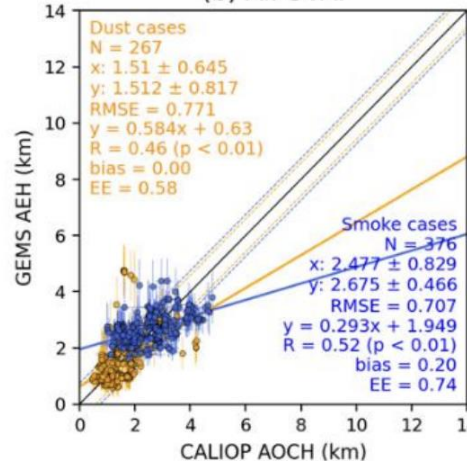


Presentation  
By J. Wang  
(1630, Mon)

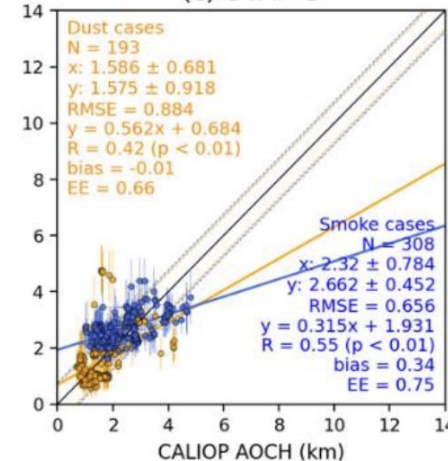
(a) Passive vs CALIOP ALH



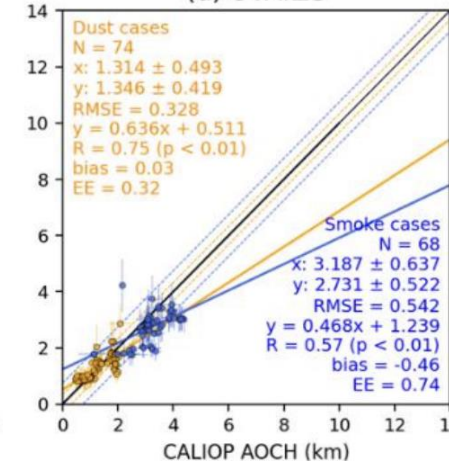
(b) All UVAI



(c) UVAI < 3

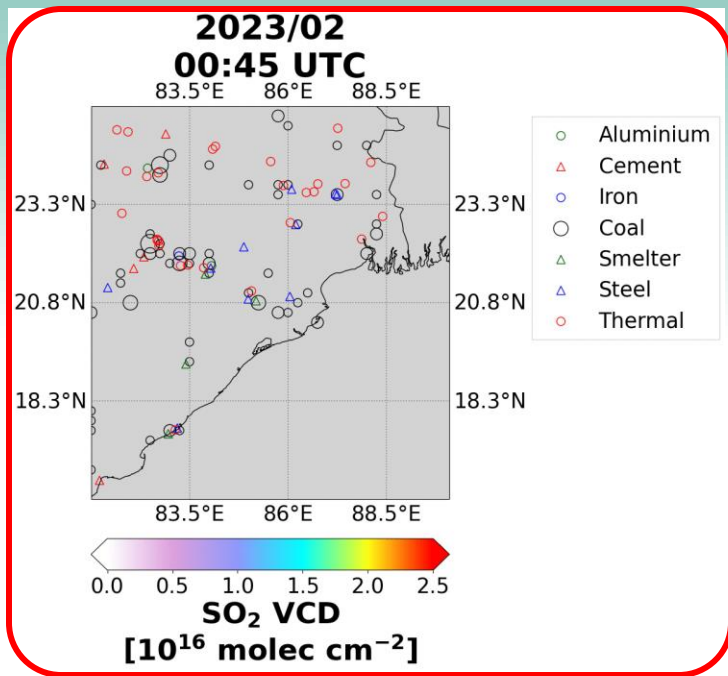


(d) UVAI ≥ 3



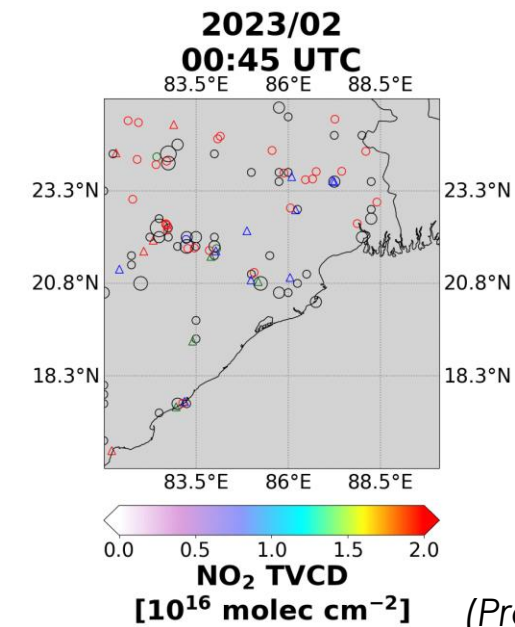
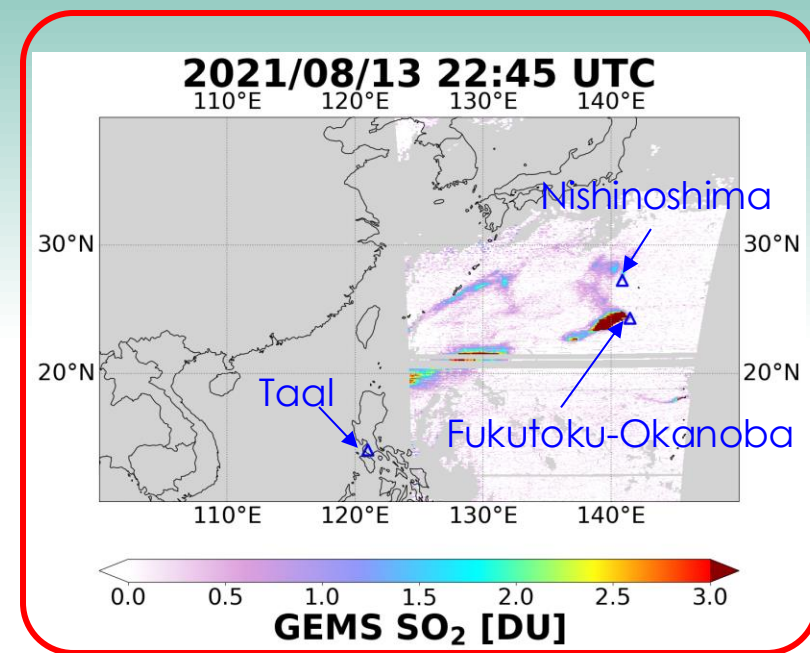


# Case studies: SO<sub>2</sub> – Coal Power Plants, Smelters & Volcanic eruption

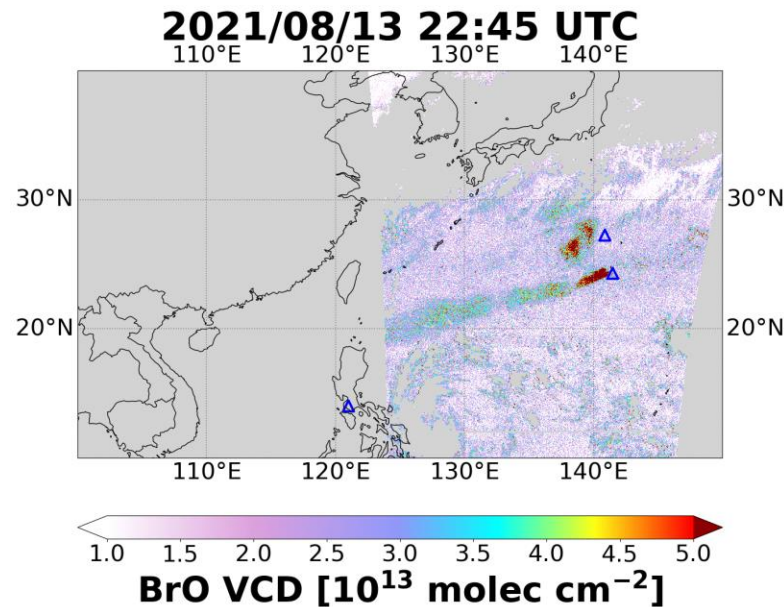
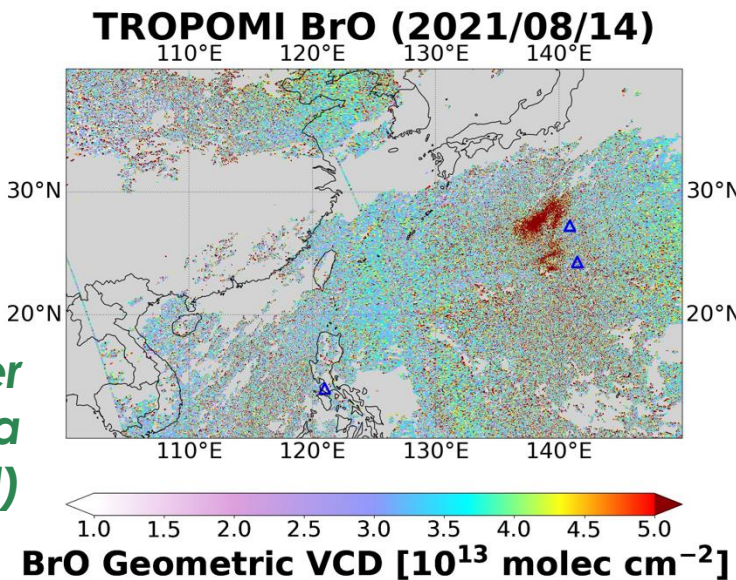


- ✓ Three volcanic eruptions (Nishinoshima and Fukutoku-Okanoba in Japan, and Taal in Philippines) on 14 Aug 2021.
- ✓ BrO were rarely detected at Taal volcano in Philippines.

*Presentation by H. Lee  
(1040, Thu)*



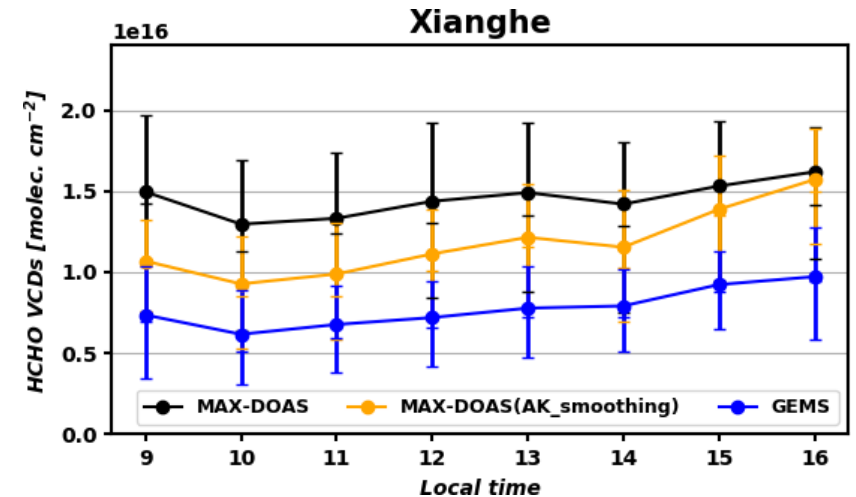
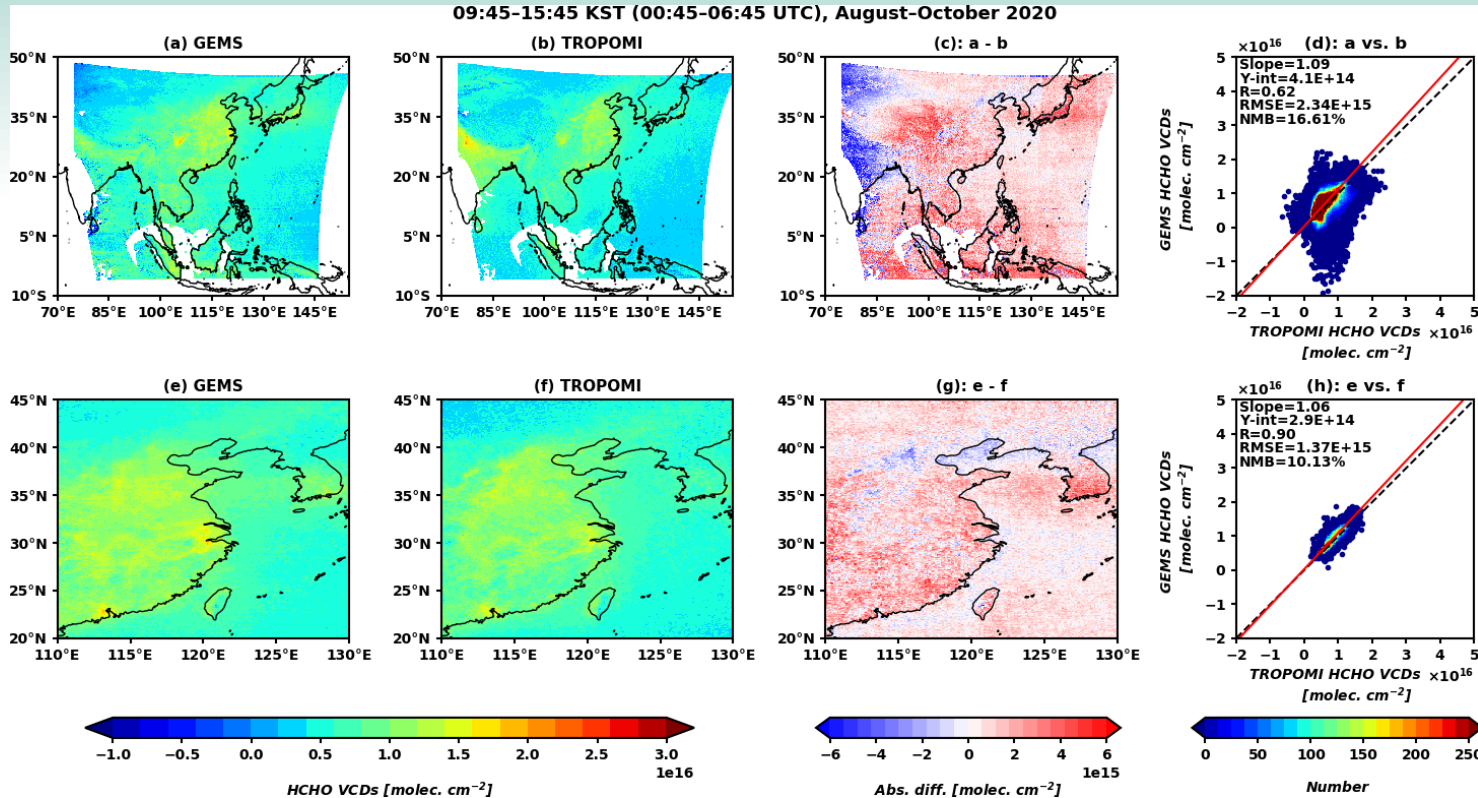
*Poster  
by H. Cha  
(#6, Wed)*



*(Prod Lead: Hanlim Lee-SO<sub>2</sub>, Jhoon Kim-BrO)*

# HCHO VCDs: GEMS vs. TROPOMI & MAX-DOAS

Presentation  
by R. Park  
(1010, Thu)



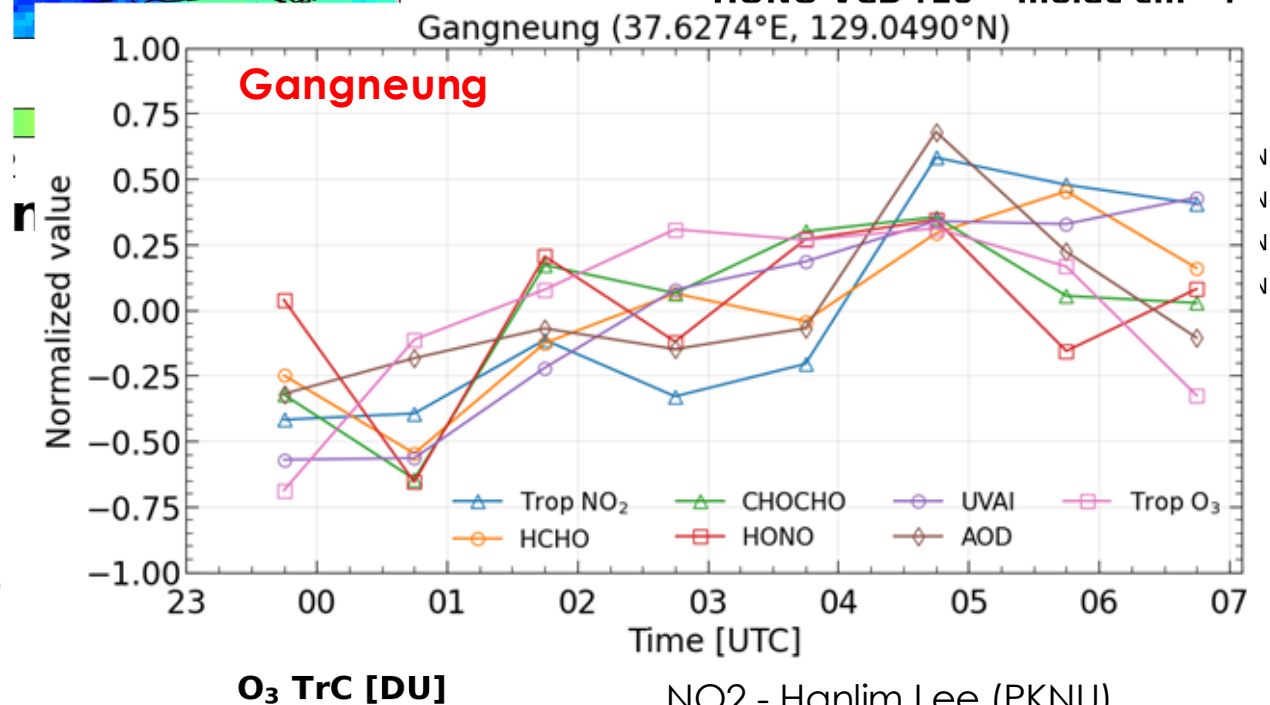
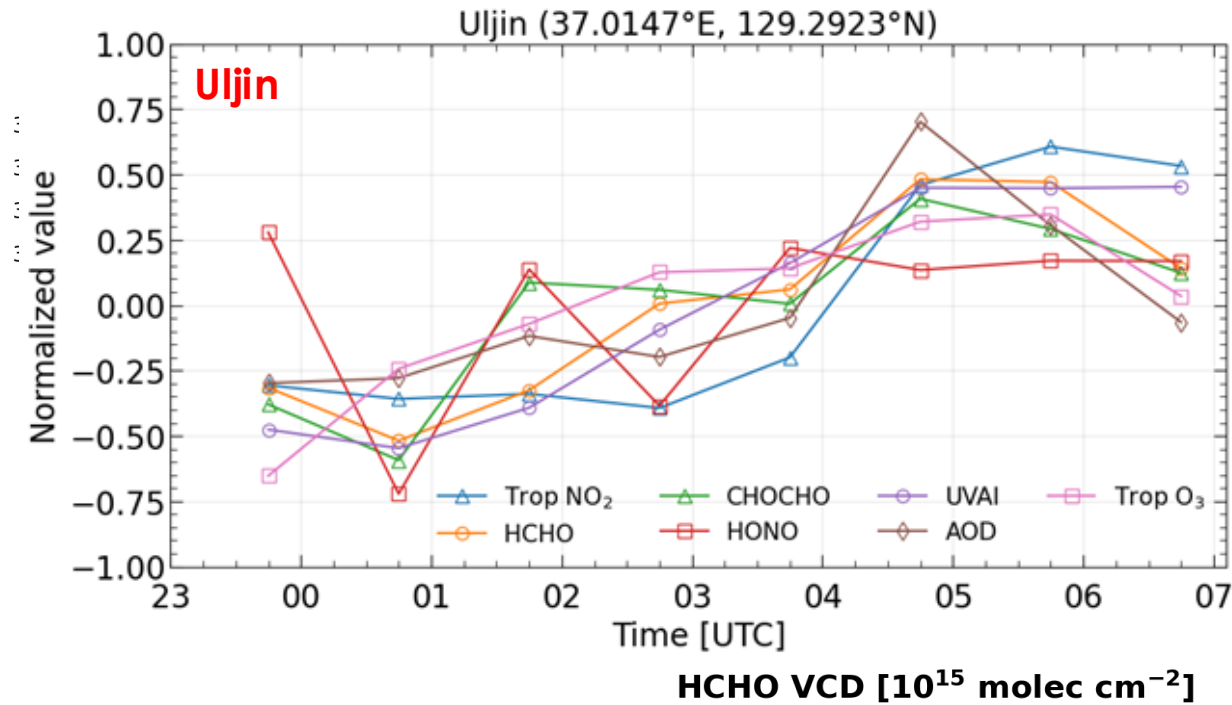
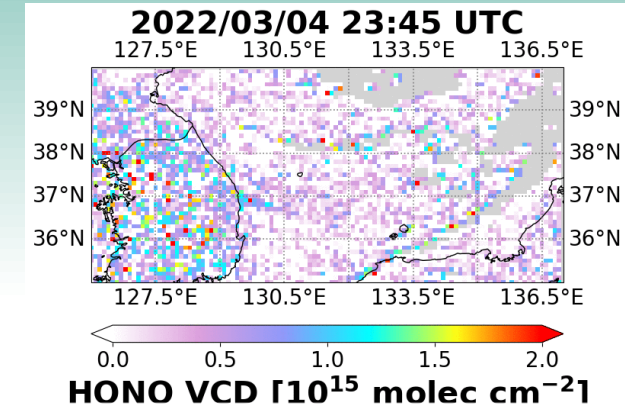
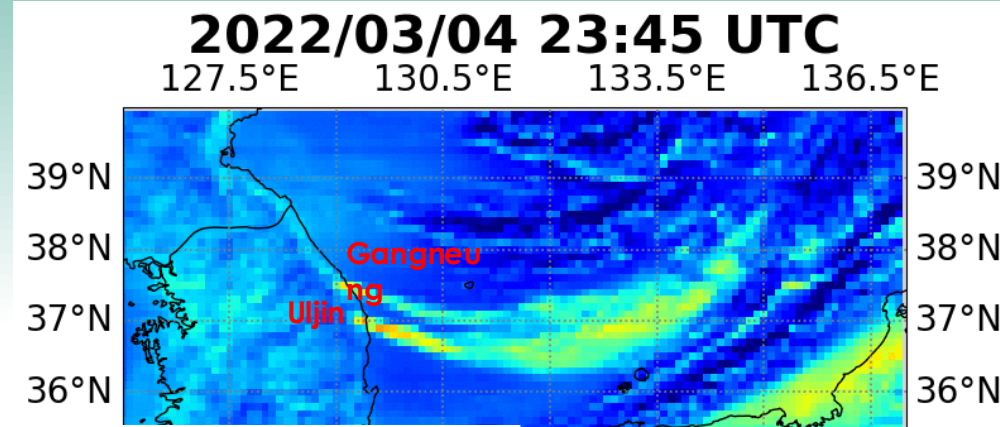
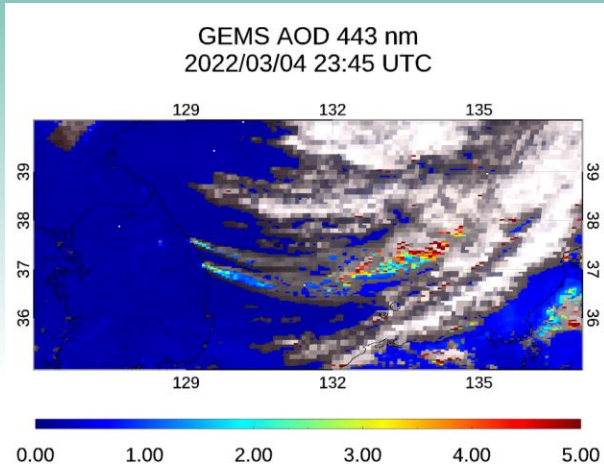
Lee et al. (*Atmos. Meas. Tech.*, 2024)

- Better agreement over East China and the Korean Peninsula ( $R=0.90$ ).
- GEMS: lower HCHO VCDs compared to TROPOMI, especially at high viewing zenith angles ( $VZA > 60^\circ$ ).

- Lower GEMS VCDs than MAX-DOAS
- Smoothing MAX-DOAS data with GEMS averaging kernel reduces bias.



# Wildfires



NO<sub>2</sub> - Hanlim Lee (PKNU)  
HCHO, CHOCHO - Rokjin Park (SNU)  
O<sub>3</sub> - Jae Kim (PNU)  
HONO, Aerosol - Jhoon Kim(YSU)

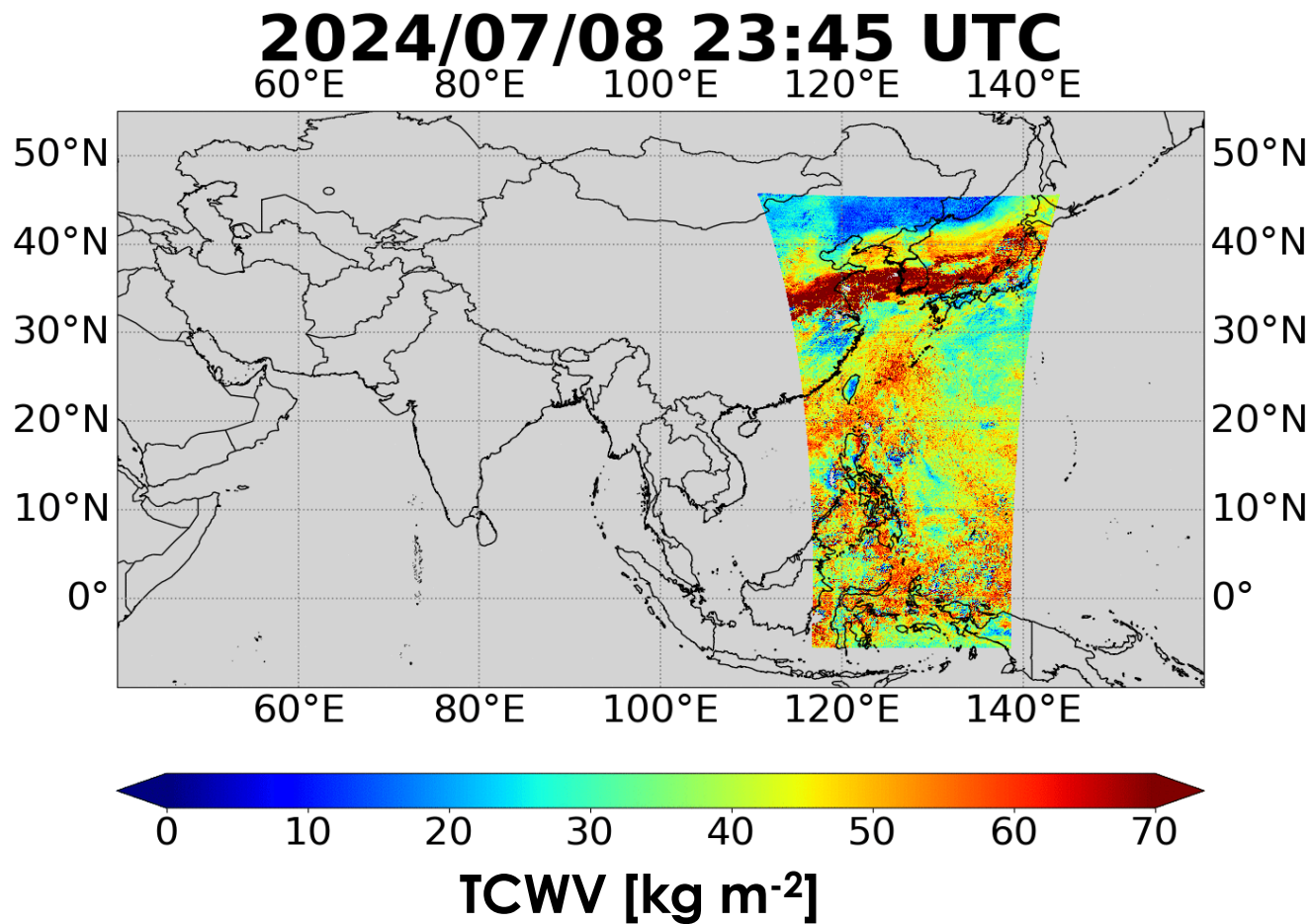
- ✓ Large wildfires in Uljin and Gangneung, South Korea on 5 March 2022.
- ✓ Clear enhancements of UVAI, AOD, HCHO, CHOCHO, HONO and tropospheric NO<sub>2</sub> over the wildfire plumes were detected from GEMS.



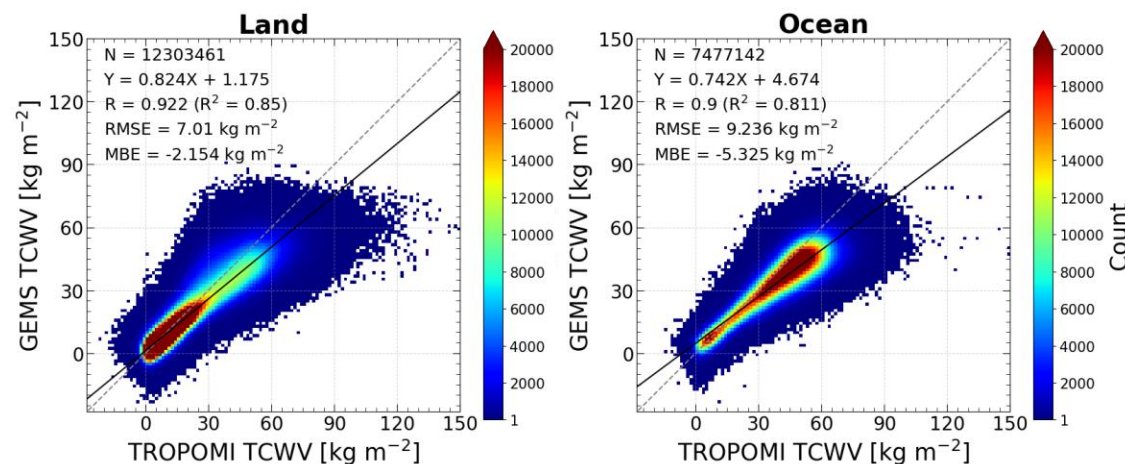
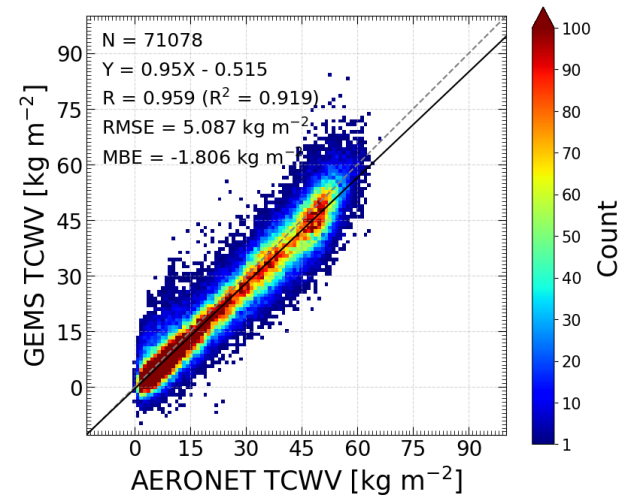
# GEMS TCWV

Poster by H. Cha (#6, Wed)

✓ Atmospheric river event over East Asia on 9 July 2024



✓ Validation period: Mar 2021 – Feb 2023 (2 years)



OH retrieval from GEMS required TCWV data (R. Park). Poster by S. Oh (#48, Wed)

# Gas Products Validation

Presentation by R. Lutz (0930, Fri)  
and many from Cal/Val Team

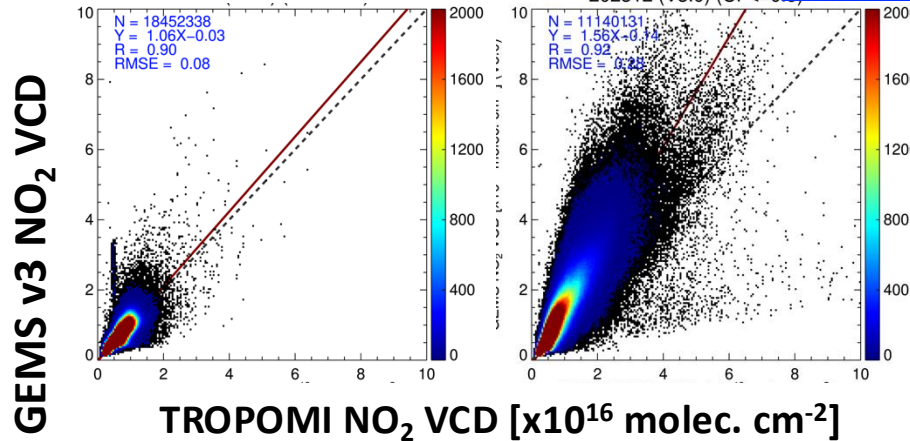
Slope = 1.06  
R = 0.90

NO<sub>2</sub> v3

2023/06

Slope = 1.56  
R = 0.92

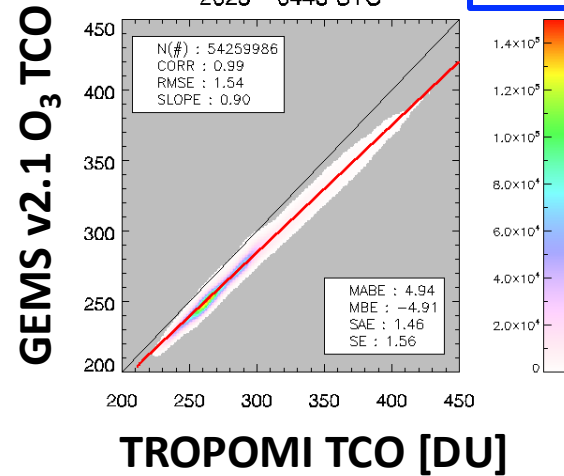
2023/12



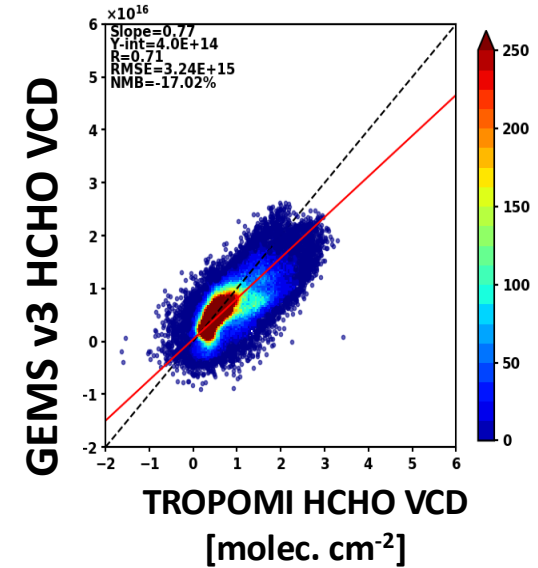
O<sub>3</sub> v2.1

2023 0445 UTC

Slope = 0.90  
R = 0.99

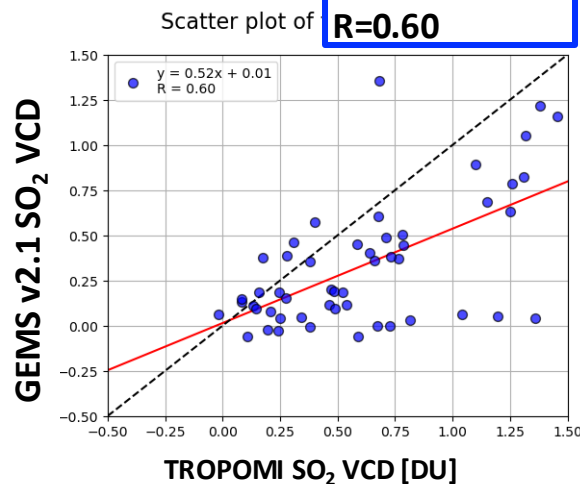


HCHO v3 [x10<sup>16</sup>]

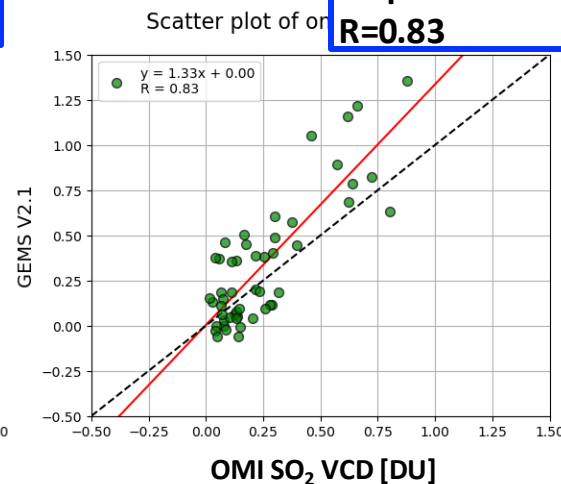


SO<sub>2</sub> v2.1

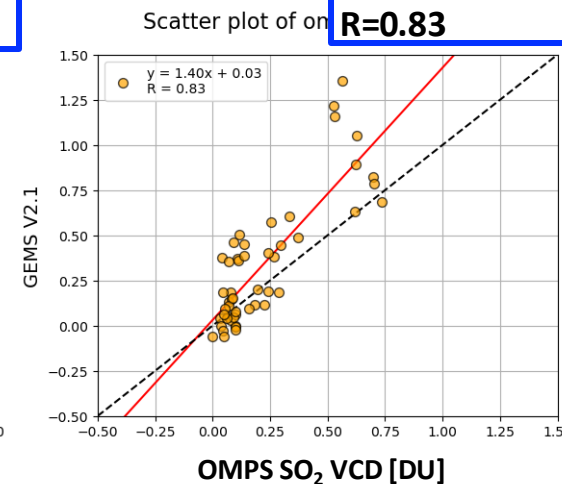
Slope = 0.52  
R = 0.60



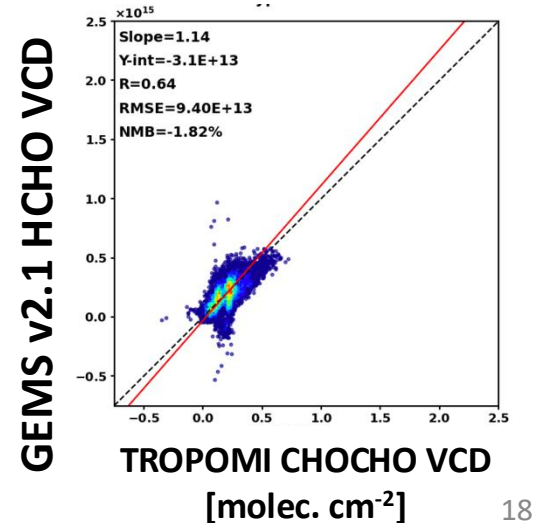
Slope = 1.33  
R = 0.83



Slope = 1.40  
R = 0.83



CHOCHO v3 [x10<sup>15</sup>]





# Aerosol, Cloud & SFC Validation

Presentation by R. Lutz (0930, Fri)  
and many from Cal/Val Team

AOD v2.1

R=0.832  
RMSE: 0.317

SSA v2.1

AEH v2.0 vs v2.1

GEMS Cloud v3

R=0.77 ~ 0.70  
RMSE: 0.16 ~ 0.20

GEMS AOD [443nm]

GEMS SSA [443nm]

GEMS AEH v2.1

GEMS v3 ECF

TROPOMI DLER

AERONET AOD [443nm]

AERONET SSA [443nm]

GEMS AEH v2.0

TROPOMI ECF

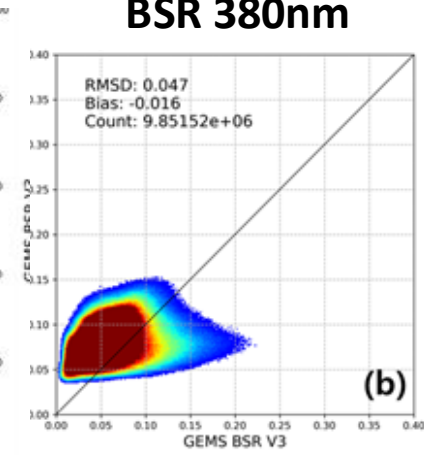
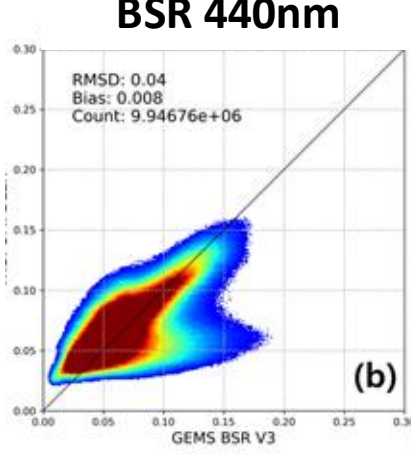
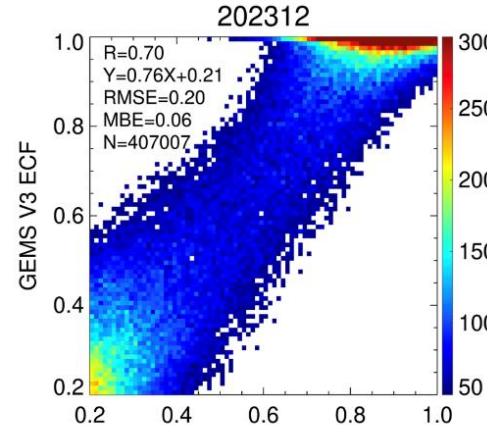
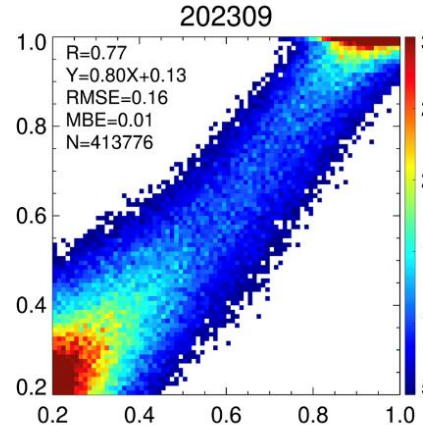
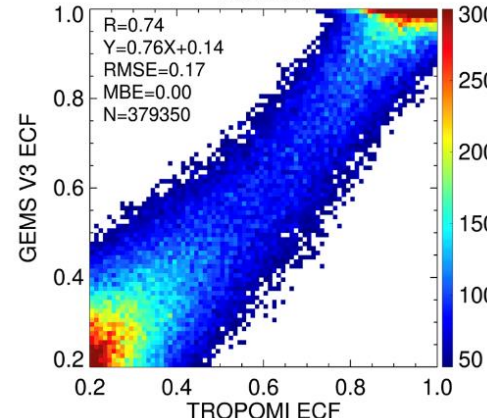
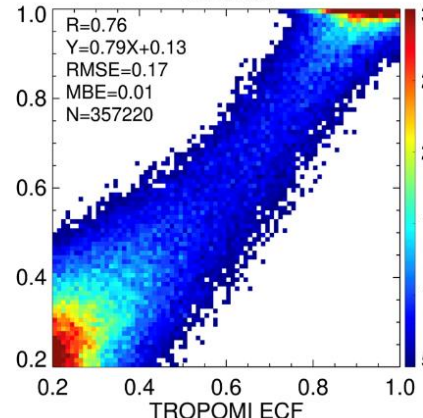
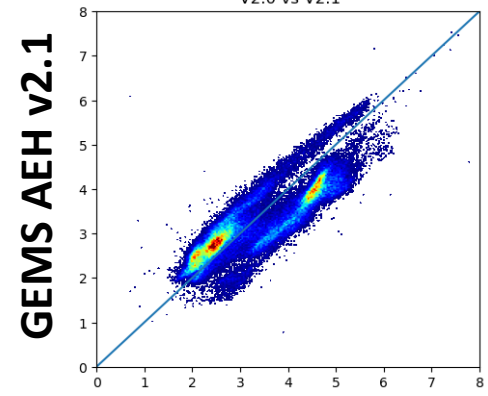
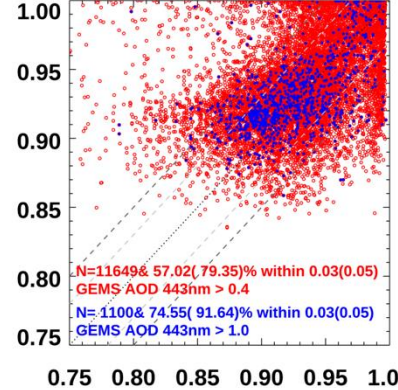
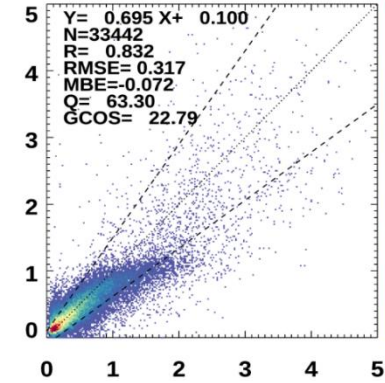
TROPOMI ECF

BSR 440nm

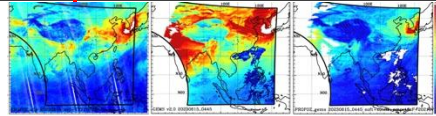
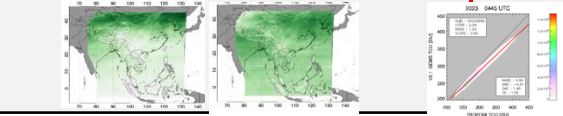
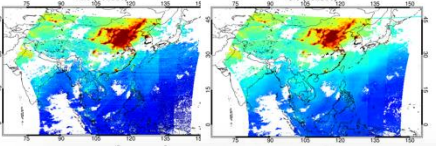
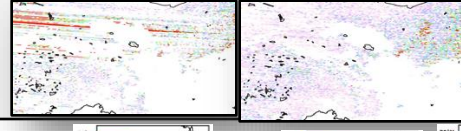
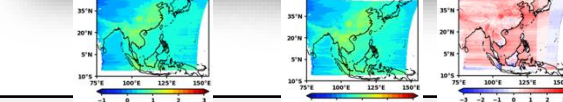
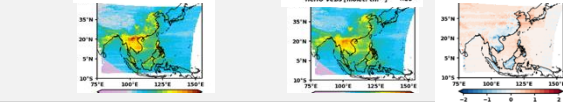
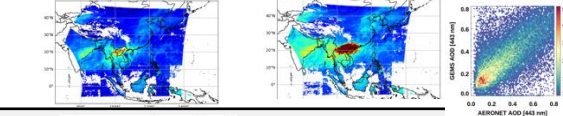
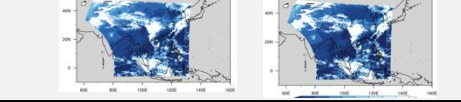
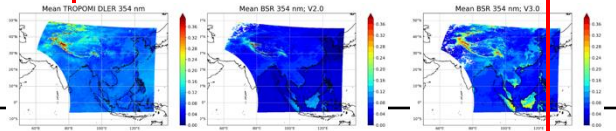
BSR 380nm

GEMS BSR v3

TROPOMI ECF



# Update to version 3

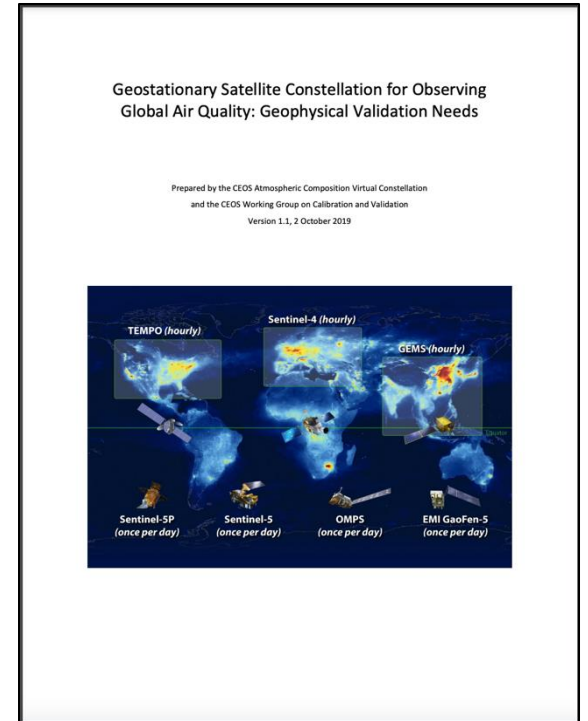
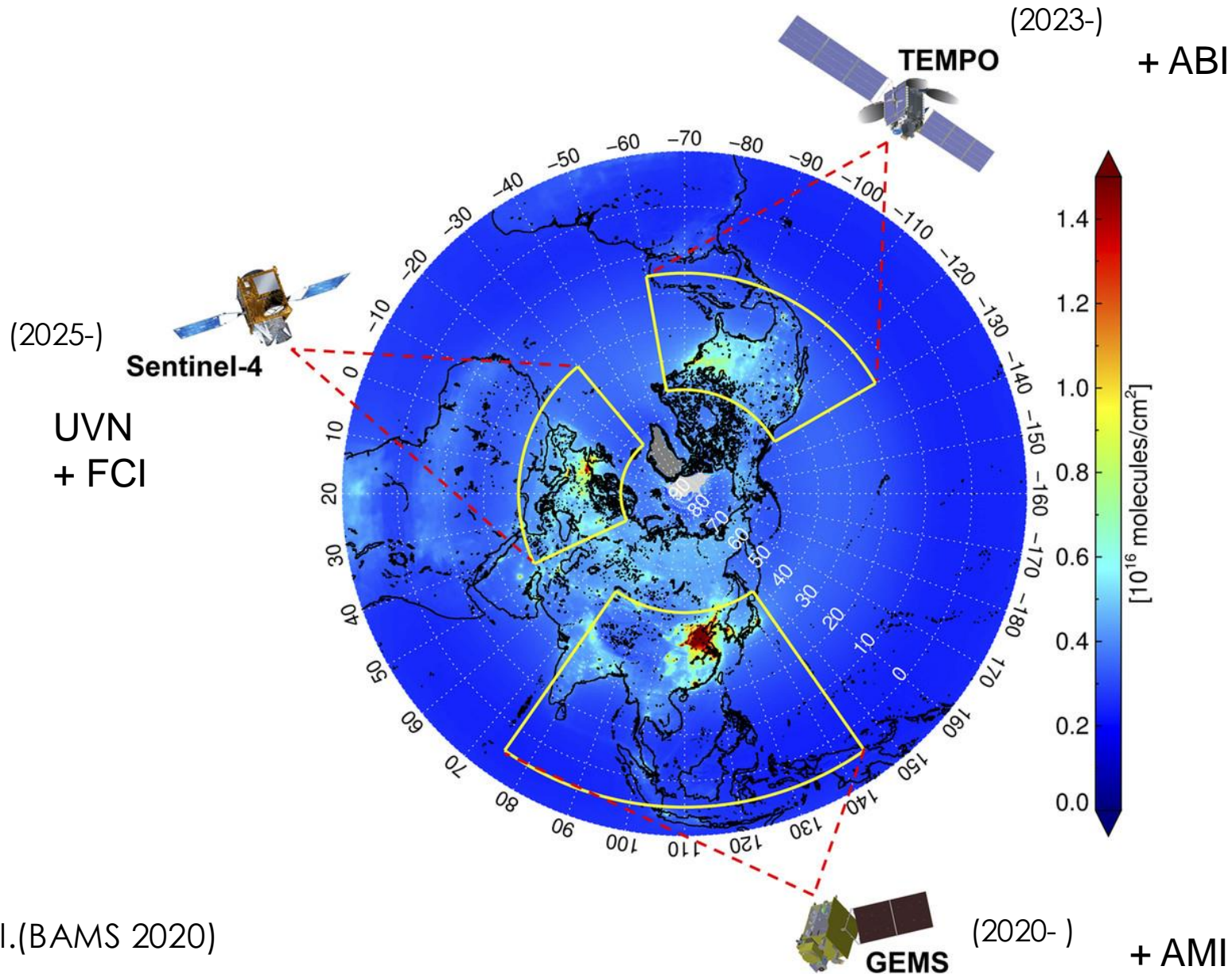
Prod	V2 Issue	Update details	TROPOMI V2	V3	Val	Presentation
Trop O3	Overestimation	Fitting window, Optimize L1 cal Data (Spectroscopy, Met, Solar Ref)				Jae Kim (1020, Thu)
Strat O3	Underestimation	LUT Data (CLD)				Jae Kim (1020, Thu)
NO2	Overestimation Profile shape Tropopause height	AMF S-T separation smoothing Data (AOD, O3T, CLD, BSR)				Y. Jung (1030, Thu)
SO2	Stripe (H) Noise (L)	Slit Function (2x2 pixel binning) SO2 profile				H. Lee (1040, Thu)
HCHO	average model conc Underestimation(W)	Variable background conc Data (BSR)				R. Park (1010, Thu)
CHO CHO	average model conc	Background correction Data (BSR, CLD)				R. Park (1010, Thu)
AOD	Underestimation ALH at 2km	Extend LUT, Background AOD, AI Min LER composite to 3 years				Y. Chai (#7, Wed)
CLD	ECF: Overestimation CCP: lower-layer	LUT, interpolation Clear sky CCP as sfc P, Data (SFC)				G. Kim (1010, Fri)
SFC	Underestimation <400nm Overestimation @380nm	Interpolation in rad & irr Option handling for IRR, Modification				S. Shim (1040, Fri)



# After applying BTDF-corrected Irradiance

	Stripe issue	Overestimation/Underestimation	Note
O <sub>3</sub> Total	X	-	<ul style="list-style-type: none"> <li>The <b>negative bias</b> has shifted to a <b>positive bias</b></li> <li>Absolute value of the <b>bias</b> has <b>decreased</b></li> </ul>
O <sub>3</sub> Profile	O	overestimation	<ul style="list-style-type: none"> <li><b>Stripe issue</b> in the 10-30° N</li> <li>If the irradiance offset is not applied, it results in an <b>overestimation</b> of tropospheric O<sub>3</sub></li> </ul>
SO <sub>2</sub>	O	-	<ul style="list-style-type: none"> <li>The <b>stripe issue</b> has <b>increased</b> in the ranges of 15-30° N and around 0° N</li> </ul>
NO <sub>2</sub>	O	-	<ul style="list-style-type: none"> <li>The <b>stripe issue</b> still exists</li> <li><b>NO<sub>2</sub></b> VCDs have <b>decreased</b> over <b>high NO<sub>2</sub></b> areas</li> </ul>
HCHO	X	-	<ul style="list-style-type: none"> <li><b>Increase</b> in HCHO VCDs of over 8% in <b>Jan</b> and <b>Fab</b> is expected to <b>improve</b> the underestimated winter values</li> <li><b>Decrease</b> in HCHO VCDs in the <b>south</b> and <b>increase</b> in the <b>north</b></li> </ul>
CHOCHO	O	overestimation	<ul style="list-style-type: none"> <li><b>Stripe issue</b></li> <li><b>Increase</b> in <b>winter</b>, where there was an issue of CHOCHO <b>overestimation</b></li> </ul>
AOD	X	bias	<ul style="list-style-type: none"> <li><b>Overestimation</b> of AOD due to a degradation issue</li> </ul>
AEH	X	-	<ul style="list-style-type: none"> <li><b>Overestimation</b> of AEH has <b>decreased</b></li> <li>AEH output range is more <b>stable</b></li> </ul>
SFC	X	-	<ul style="list-style-type: none"> <li>The <b>stripe issue</b> that occurred when using KNMI has been reduced</li> <li>The <b>low BSR</b> calculated with KNMI has <b>stabilized</b> to reliable values when using BTDF IRR</li> </ul>
CLD	O	-	<ul style="list-style-type: none"> <li><b>Stripe issue</b> does not occur with ECF, but occurs with <b>CCP</b></li> <li>Stripe issue in CCP mainly occurs in the lower layers and appears regardless of latitude</li> </ul>

# GEO Constellation of Air Quality Observation

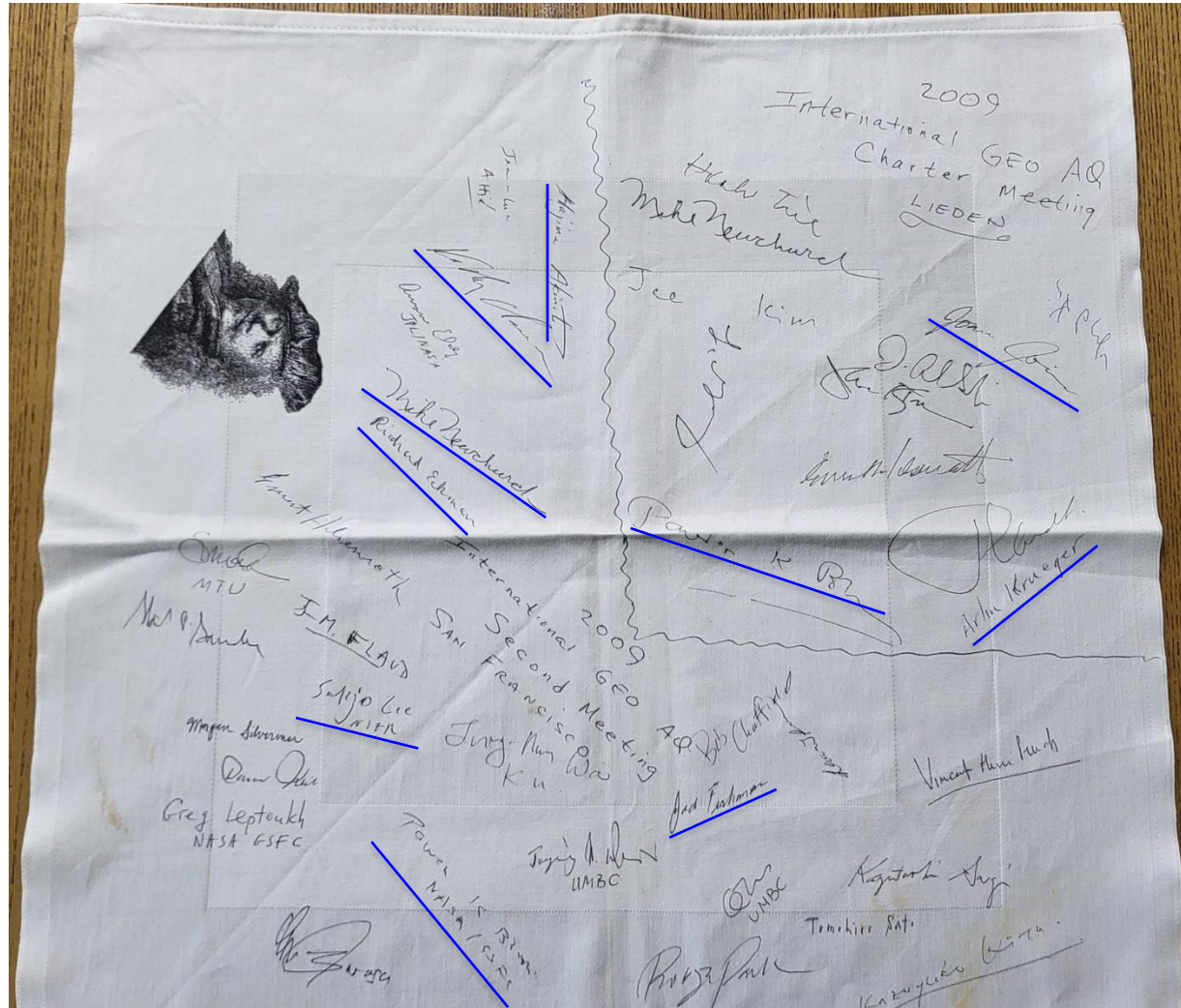


CEOS AC-VC (2019)

Background image:  
10-year average NO<sub>2</sub>  
column density  
from OMI (2005-2014)



# The First Agreement for International Collaboration in GEO AQ



Signed in 2009; Received in 2023;  
Kept over 10 years by Mike Newchurch



# 21 Papers in GEMS Special Issue for ACP/AMT



## Atmospheric Chemistry and Physics



## Atmospheric Measurement Techniques

ARTICLES & PREPRINTS ▾ SUBMISSION POLICIES ▾ PEER REVIEW ▾ EDITORIAL BOARD ABOUT ▾ EGU PUBLICATIONS ↗

# Special issue

Articles / Special issue

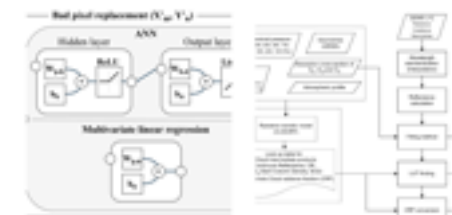
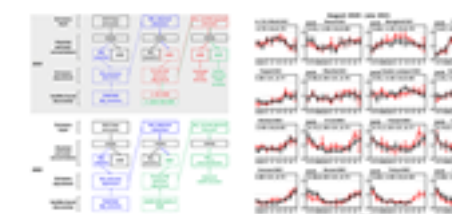
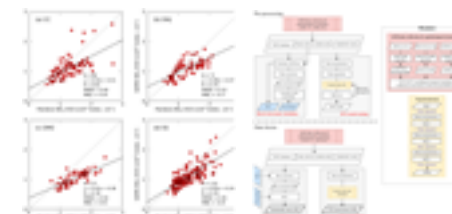
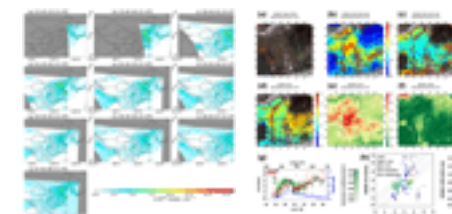
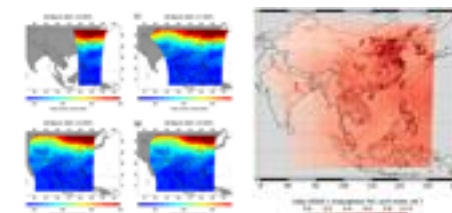
Search



### ► [GEMS: first year in operation](#) (AMT/ACP inter-journal SI), 2022

**Eds.** ACP co-editors | **Coordinators:** Chul Han Song and Farahnaz Khosrawi | **Co-organizers:** Jhoon Kim, M. H. Ahn, Rokjin Park, Ben Veihelmann, and Pawan K. Bhartia

Geostationary Environment Monitoring Spectrometer (GEMS) is the first instrument to observe air quality from a geostationary Earth orbit (GEO) successfully launched on 19 February 2020 and in initial operation after in-orbit tests (IOTs). GEMS provides hourly air quality information on both aerosols and gases at unprecedented spatial resolution of 7 km × 8 km. GEMS is a scanning UV–visible spectrometer measuring the hyperspectral spectrum in the ultraviolet and visible, which allows for the observation of key atmospheric constituents including O<sub>3</sub>, NO<sub>2</sub>, CO, SO<sub>2</sub>, CH<sub>2</sub>O, CHOCHO, aerosols, clouds, and UV indices. The mission opened a new era of air quality monitoring from space and will be joined by NASA’s TEMPO and ESA’s Sentinel-4 to form the GEO Air Quality Constellation in ~3 years to cover the most polluted region in the Northern Hemisphere. In this ACP–AMT special issue, the first results will be presented including instruments, IOT results, initial products, algorithm, calibration, validation from the recent

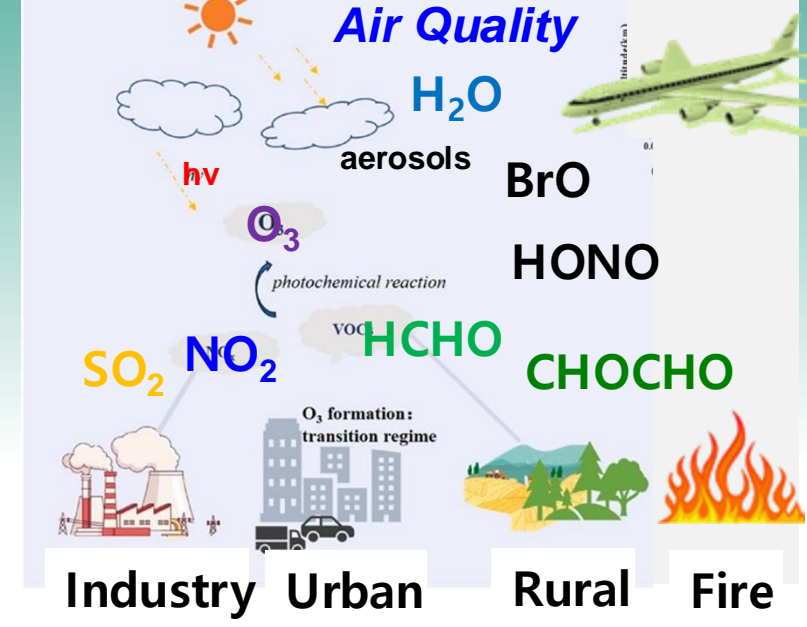
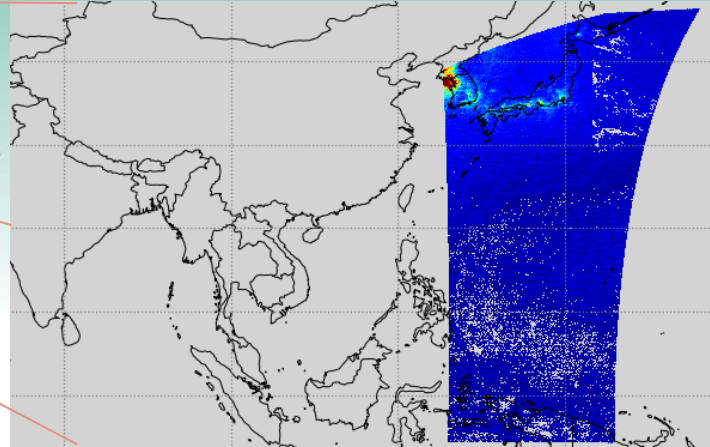




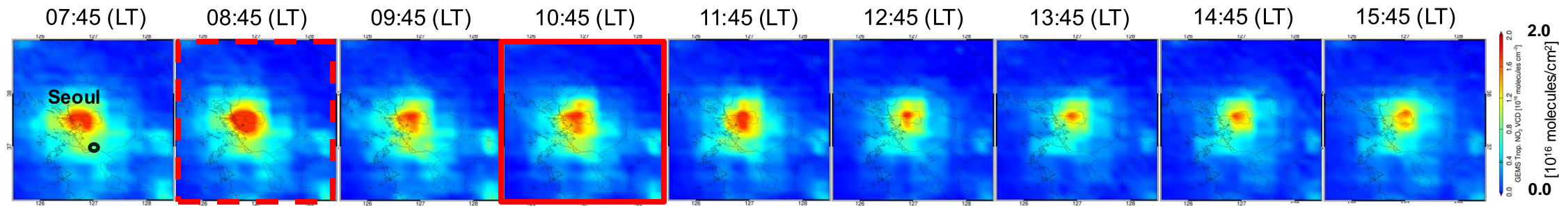
# Summary



**GEMS**  
in successful operation  
since 2020

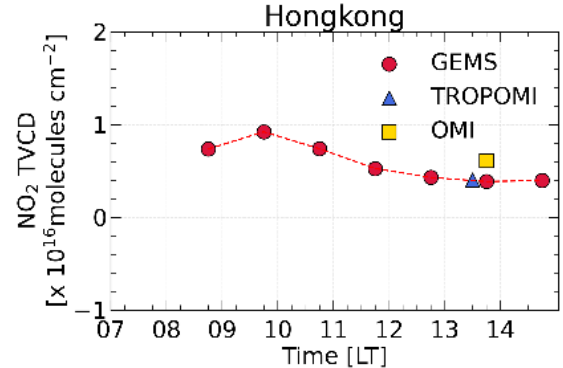


## Diurnal variations – Conc & Spatial

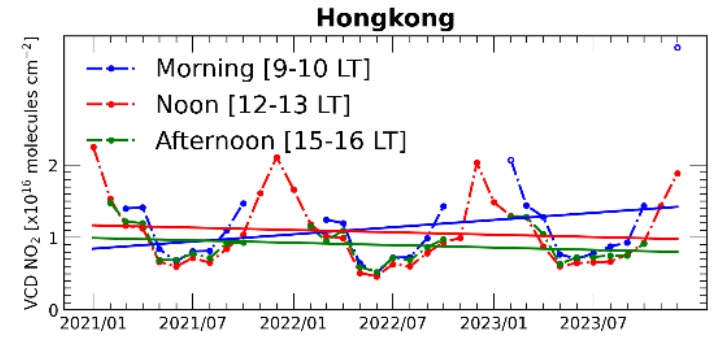


Park et al. (submitted)

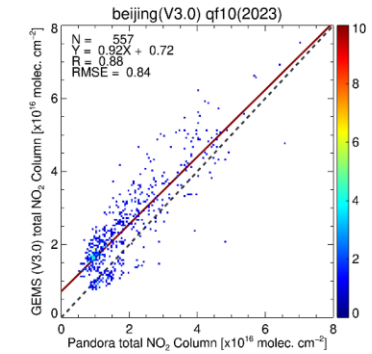
## Diurnal variations - Temporal



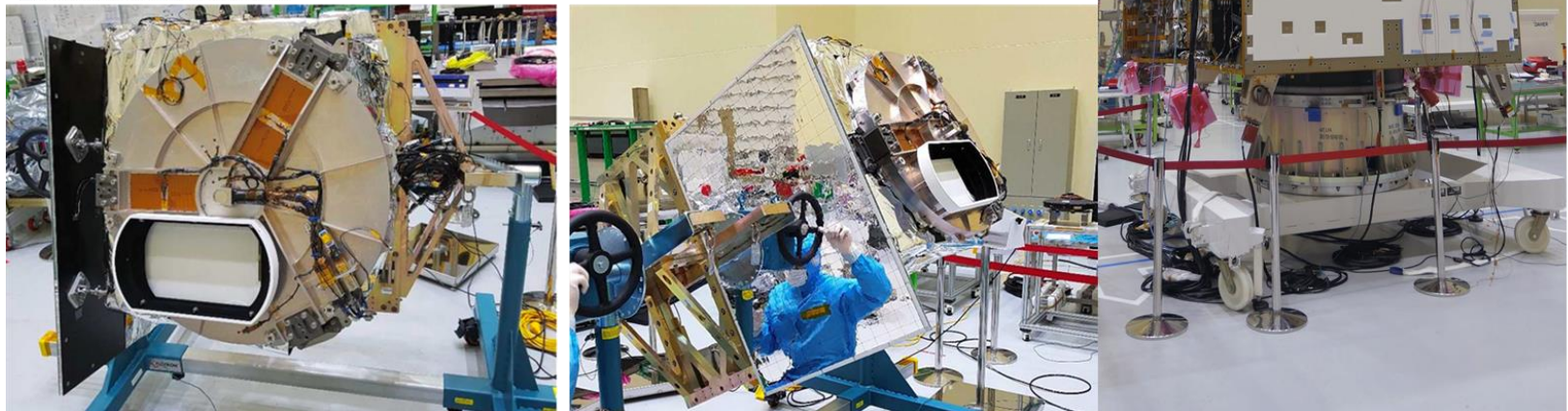
## Long-term trends for AM, noon, & PM



## Validations



# Acknowledgements



**Thank you  
for all your  
contribution,  
dedication,  
and  
support !**